DOBLE TANGENTIAL WATER WHEELS

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WATER WHEELS

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DOBLE PATENTED NEEDLE REGULATING NOZZLES
DOBLE PATENTED ELLIPSOIDAL BUCKETS
DOBLE HIGH-SPEED RING-OILING BEARINGS

MANUFACTURED BY

ABNER DOBLE COMPANY

ESTABLISHED 1850

ENGINEERS

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MONTREAL, CANADA

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INTRODUCTION

Since the entrance of the Abner Doble Company into the field of hydraulic engineering, when its initial work was as consulting and advisory engineers, the attention of the company has been largely devoted to power plant engineering with special reference to hydro-electric development. Up to that period, we had not entered extensively into the manufacture of water wheels, or other hydraulic machinery. We did so then, only because the market did not afford machinery of a sufficient high grade, to conform with the designs and specifications, which we, as engineers, deemed necessary for the work in hand.

As there were no high-grade water wheels made at that time, we were compelled to manufacture them ourselves. This led to the design and development of the Doble Ellipsoidal Bucket, the Doble Needle Regulating Nozzle, and other essential parts. By applying such parts to the Tangential type of water wheel, combined with the use of the highest grade of materials and the most skilled workmanship, we produce a water wheel which is thoroughly durable and has a high operating efficiency.

Although still strictly maintaining our identity as engineers, particularly in the hydraulic field, it has always been our aim, in prosecuting any engineering work, to adapt the machinery which we specify to the local conditions. Consequently, whenever we have found that by the working out of certain details, or the construction or remodeling of particular features, the design as a whole could be made more efficient and durable, we have undertaken to build such machinery or parts in our own shops. Our clients are thus given the benefit of our extended experience as engineers, as well as afforded the advantage of securing machinery from a well-equipped shop, employing none but the most skilled workmen.

The introduction of the Doble Tangential Water Wheel has been the direct cause of a remarkable development in hydro-electric engineering and construction, and, because of the high standards which we originally established, a demand was created for water wheels of the highest efficiency, the closest regulation, and the strictest economy of maintenance. We have continued to do pioneer work in the development of the tangential type of wheel, all the improvements which have been made in its design and construction having originated with us. Our original work has been particularly noticeable in the introduction of wheels of large capacities, securing close speed regulation, and showing the highest efficiency in the use of water.

The Doble Tangential Water Wheel is the result of scientific investigation and experiment, sustained by practical application, and accurate mechanical and hydraulic tests. It has been demonstrated, that the greatest amount of effective power from the least amount of applied energy has been secured from the Doble type of tangential water wheel, i. e., the efficiency is greater than that of any other water wheel.

In the construction of wheels for various conditions of service, we have been singularly successful, and have built wheels to operate under heads from 25 feet up to 2,200 feet and in capacities up to 9,000 horse-power, these having single wheel runners taking water from a single jet.

Doble wheels are now being used by the largest power-transmission companies on the Pacific Coast. In many power plants, by reason of their higher efficiency and greater durability, they have replaced wheels of other makes.

We are in a position to manufacture anything in the tangential water wheel line, and invite attention to the descriptions and illustrations in this Bulletin. Our types of wheels are by no means limited to those shown, as our apparatus is all specially designed to secure the highest efficiency from the water available, and to meet the operating conditions of the particular plants. **We make no merchandise machinery.**

Following the descriptive matter in this Bulletin will be found the Doble Water Wheel Tables, several pipe and reference tables, conversion factors, and useful hydraulic information.

We trust that the contents will prove of value to our readers, and that the Bulletin may be retained as a book of reference.

ABNER DOBLE COMPANY

NOTICE TO CORRESPONDENTS

If any of our readers desire additional information in regard to our water wheels, or wish to make inquiries with reference to proposed installations, we would respectfully solicit their further correspondence. Upon receipt of information covering the conditions to be met, we shall be pleased to prepare estimates, and submit details and specifications, of an arrangement particularly adapted to the requirements. An outline of such information as should be furnished, for the preparation of estimates, will be found on pages 63 and 64, with a blank data sheet opposite. Extra data sheets will be furnished upon request.

CANADIAN LICENSEE

We take pleasure in announcing that arrangements have been made with the John McDougall Caledonian Iron Works Company, Ltd., of Montreal, Canada, whereby this long-established company becomes our sole licensee for the manufacture of the Doble System of Water Wheels in the Dominion of Canada and Newfoundland. The McDougall Company has extensive machine works, and its plant is well equipped for the manufacture of water wheels and other hydraulic machinery. Our Canadian licensee is prepared to furnish the steel pipe, structural work, and machinery necessary for complete power plants, and has retained the Abner Doble Company as consulting engineers. We request that all engineers or parties interested in water-power developments in Canada, address the McDougall Company direct.

CONTRACTS FOR COMPLETE POWER PLANTS

By reason of our long experience in power plant work, and our particularly favorable connection with many of the largest manufacturing establishments, we are in a position to execute contracts for complete hydro-electric, steam and gas power plants, and long-distance transmission systems. We make a specialty of designing and rebuilding plants where economy in fuel is an object, and respectfully solicit correspondence with parties engaged in new construction, as well as those desirous of improving old properties.

CONSULTING ENGINEERING DEPARTMENT

Our Consulting Engineering Department is well organized, and embraces on its staff men who have had wide experience in power plant and general engineering work. We are prepared to make the necessary preliminary and other engineering determinations, prepare designs, plans, estimates, and specifications for power plants, pumping plants, and other engineering work. We take entire charge of the construction, guaranteeing maximum economy and efficiency in construction and operation. By reason of our favorable location on the Pacific Coast, and long experience in water-power work, we are particularly well prepared to design, construct, and place in operation hydro-electric power plants for both high and low heads, and long-distance transmission systems. We frequently are called in to act in an advisory capacity where there is an engineering staff already established, or where other consulting engineers have been retained.

TURBINES

In many cases, where the available head is low, especially if there is a large quantity of water, it may be more economical to install turbines. We are in a position to furnish turbines of the most modern designs, and of the highest operating efficiency. By reason of our long and extensive experience in the designing of hydro-electric power plants, we are able to install equipment which will best meet the conditions and give the best results.

All parties, therefore, whose hydraulic developments may require the use of turbines, are respectfully requested to send us complete data in order that we may prepare suitable estimates to cover their conditions. An outline of the information required will be found on pages 63 and 64.

If there is doubt as to whether a certain proposition would seem to require tangential wheels or turbines, state the conditions as fully as possible, and we will recommend the equipment which, from an engineering standpoint, would be best suited.

DOBLE WATER WHEEL EXHIBIT AT THE ST. LOUIS WORLD'S FAIR

AWARDED THE GRAND PRIZE

Fig. 1 illustrates the Abner Doble Company's exhibit at the St. Louis World's Fair. This exhibit was awarded the Grand Prize, the highest award given by the Exposition, and the only Grand Prize awarded for machinery manufactured west of St. Louis.

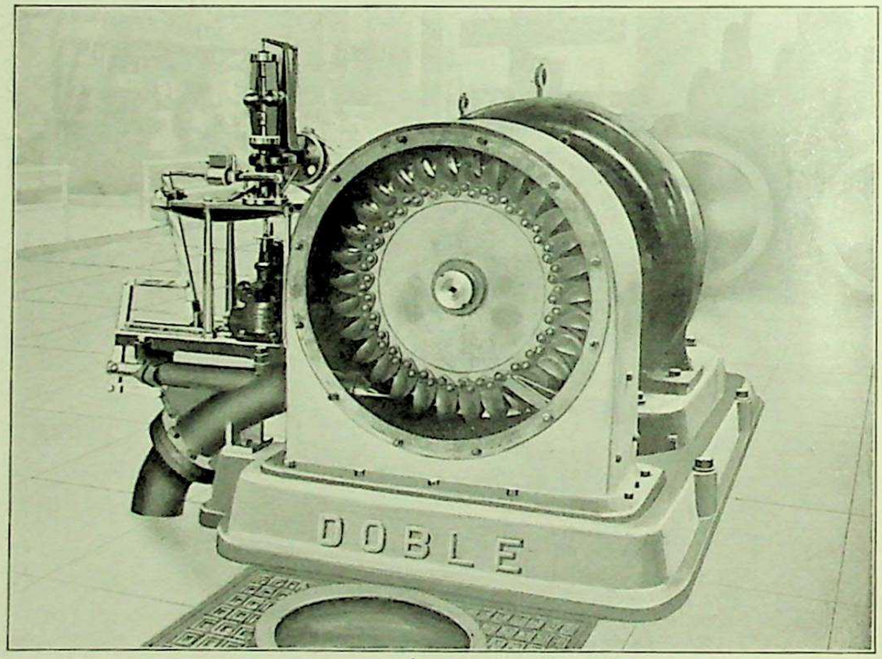

Fig. 1.

DOBLE WATER WHEEL EXHIBIT AT ST. LOUIS WORLD'S FAIR.

The exhibit was an operating one, and consisted of a 170-horse-power Doble Tangential Water Wheel. The details of its installation were carried out in a thoroughly scientific manner, and the successful working of the exhibit, from the time of its installation until the closing day of the exposition, formed one of the most interesting, as well as the most instructive, features in Machinery Hall.

The hydro-electric unit was an excellent illustration of the manner in which electricity is generated in high-head water-power plants on the Pacific Coast and elsewhere, and in fact was a typical water-power plant in itself. It is interesting to note that this was the first time that a water wheel had been shown in actual operation and doing useful work at a world's exposition.

Water, under the hydraulic pressure necessary, was furnished by a duplex triple-expansion mining pump, because no natural high head of water was available at St. Louis. This pump supplied the water to the wheel under a pressure equal to a head of 700 feet, its capacity being 1,200 gallons per minute.

The wheel was directly connected to a 100-kilowatt railway-type generator, furnishing direct current at 550 volts to the feeder system of the Intramural Railway power plant. The speed of the unit was 700 revolutions per minute. Constant speed was maintained by means of a hydraulic governor.

The hydro-electric unit was of the two-bearing type, the water wheel being mounted on the extended end of the generator shaft. This two-bearing type of construction originated with the Abner Doble Company, and is now being generally adopted in modern water-power plants.

The wheel was of particular value as an exhibit, as it illustrated the standard construction of the Abner Doble Company, being built for commercial operation according to our regular practice.

In order that the action of the water on the buckets, as well as the perfect form of the jet issuing from the needle nozzle, might be observed at all times, the sides of the water-wheel housing were constructed of plate glass.

The water wheel was equipped with Doble Ellipsoidal Buckets, made of selected gun-metal castings. The stream of water used to drive the wheel under the 700-foot head issued from, and was controlled by, a Doble Needle Regulating Nozzle, actuated by the governor.

This exhibit wheel has been purchased by the University of Michigan for its Engineering Department. It is to form a special feature of the hydraulic laboratory in the University's new Engineering Building, where it will be operated by a fire pump under heads up to 580 feet.

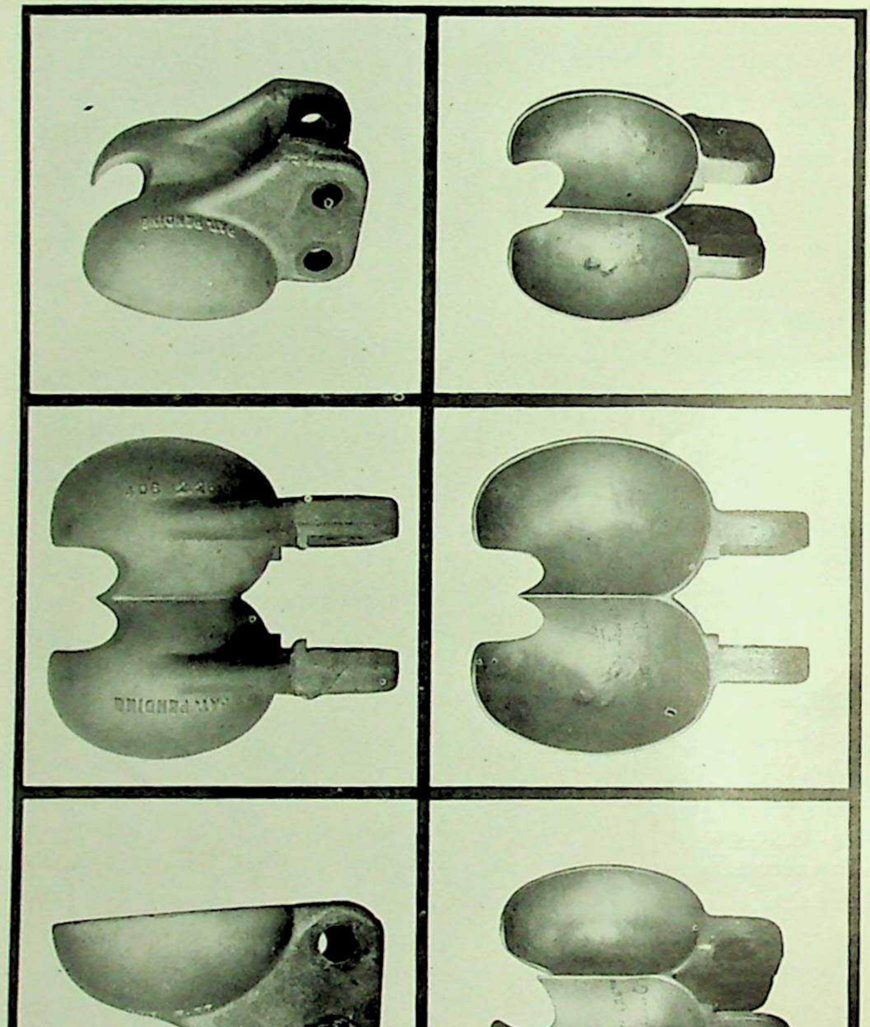

Fig. 2.

VIEWS OF A DOBLE ELLIPSOIDAL BUCKET IN SERVICE 586 DAYS UNDER 1300-FOOT HEAD

BUCKETS

Doble Ellipsoidal Buckets (Patented) are used on all tangential water wheels made by the Abner Doble Company.

The superiority of the Doble Ellipsoidal Bucket lies in the fact that because of its form, the jet of water enters without shock or disturbance, and is discharged along natural lines over the entire bucket surface. The central portion of the front entering edge or lip of the bucket is cut away in the form of a semi-circular notch. This opening allows the solid jet to impinge on the dividing wedge of the bucket without being split in a horizontal plane, and thus wastefully diverting part of the water from the wheel. With the Ellipsoidal Bucket all eddy currents are avoided, and, as the full force of the jet is spent in doing useful work, the efficiency of the bucket is very high The absence of eddy currents results in even wear and remarkable durability.

Each bucket straddles the rim of the wheel body, and the fastening lugs or flanges are milled to gauge, on a specially designed machine, so that the bucket will accurately fit the wheel on the periphery and on both sides of the rim. Each is fastened to the wheel rim by two body-bound bolts, fitted in reamed holes. Each bucket is carefully ground smooth and polished on the hydraulic surfaces, and the dividing wedge and entrance edges are accurately machined, and sharpened to a knife edge. The buckets are interchangeable, being accurately fitted, and drilled in jigs, and finally brought to the same weight, so that the wheels shall be dynamically and statically balanced.

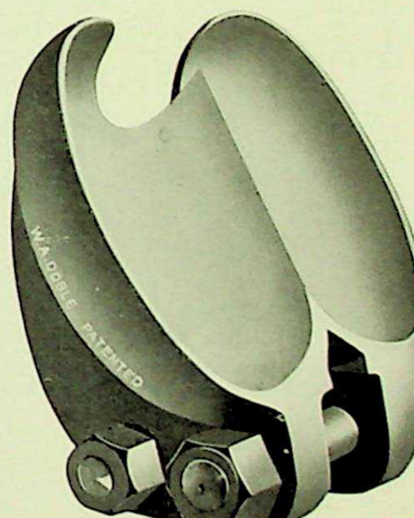

Fig. 3. DOBLE ELLIPSOIDAL BUCKET

Buckets are cast from different metals, depending principally on the head of water to be applied to the wheels. The metals used are a special mixture of close-grain cast iron, gun-bronze (United States Naval requirements) and open-hearth steel.

The condition of Ellipsoidal Buckets which have been in use for a number of years proves the correctness of the theories upon which this bucket is designed. Demonstrating this fact is the appearance of the bucket shown in the six views in Fig. 2. This bucket was in service 586 twenty-four-hour days under a head of 1,300 feet. Note the absence of irregular erosions of the hydraulic surfaces, and the absence of all wear on the back of the bucket, although the water carried much detritus.

Fig. 3 illustrates a Doble Ellipsoidal Bucket such as used on the Doble Tangential Water Wheels. Single wheels up to 9,000 horse-power capacity, and for operation under heads as high as 2,200 feet, have been built with these buckets, and are in successful operation.

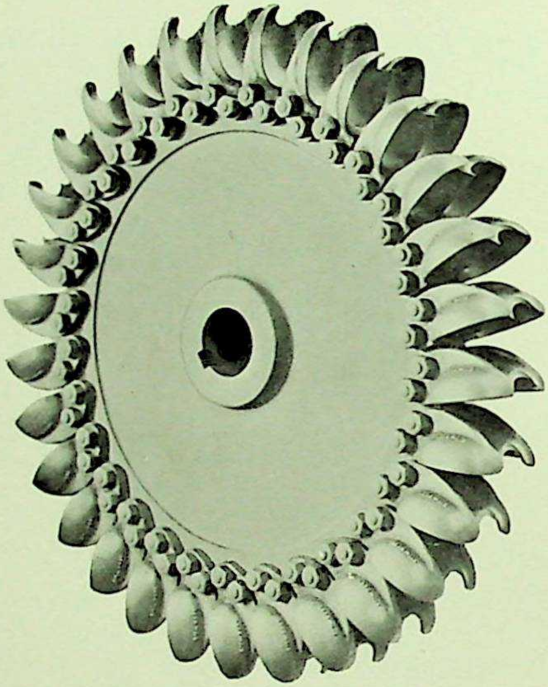

Fig. 4.

RUNNER OF DOBLE TANGENTIAL WATER WHEEL. AWARDED THE GRAND PRIZE AT ST. LOUIS WORLD'S FAIR

RUNNERS

Fig. 4 illustrates the revolving element, or runner, of the Doble Tangential Water Wheel exhibited at the St. Louis World's Fair, and which was awarded the Grand Prize. The wheel body is a semi-steel casting, finished all over and balanced. The hub is bored and key-seated to fit the generator shaft. The buckets are gun-metal castings, of the Doble Ellipsoidal type. A description of this exhibit wheel is given on pages 8 and 9.

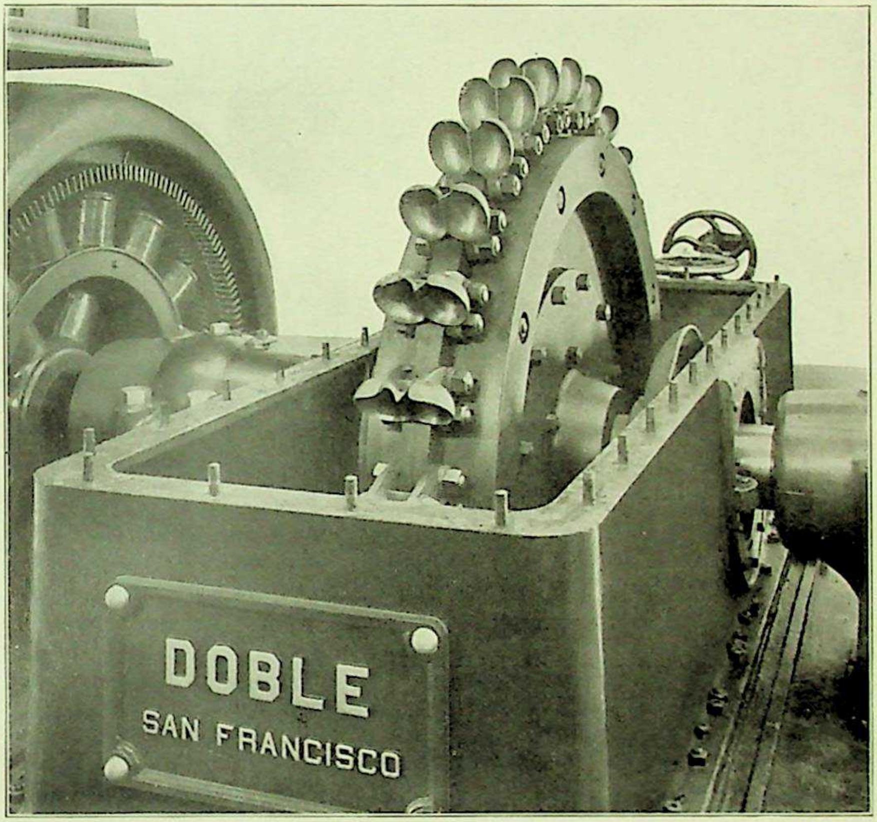

Fig. 5.

DOBLE WHEEL AFTER OPERATING OVER TWO YEARS UNDER 1960-FOOT HEAD

In Fig. 5 is illustrated a Doble Wheel installed at the Mill Creek No. 3 Power Plant of the Edison Electric Company of Los Angeles, Cal. The view shows the machine after two years and three months' continuous running under a head of 1,960 feet, at 430 revolutions per minute. Note the perfect condition of the buckets.

This wheel is one of the three Doble Tangential Water Wheels installed at the Mill Creek Plant, each having a capacity of 1,300 horse-power. These wheels have now been operating for over two years under a pressure of over 850 pounds to the square inch, and although the water at times carries considerable sand, the buckets show but little wear.

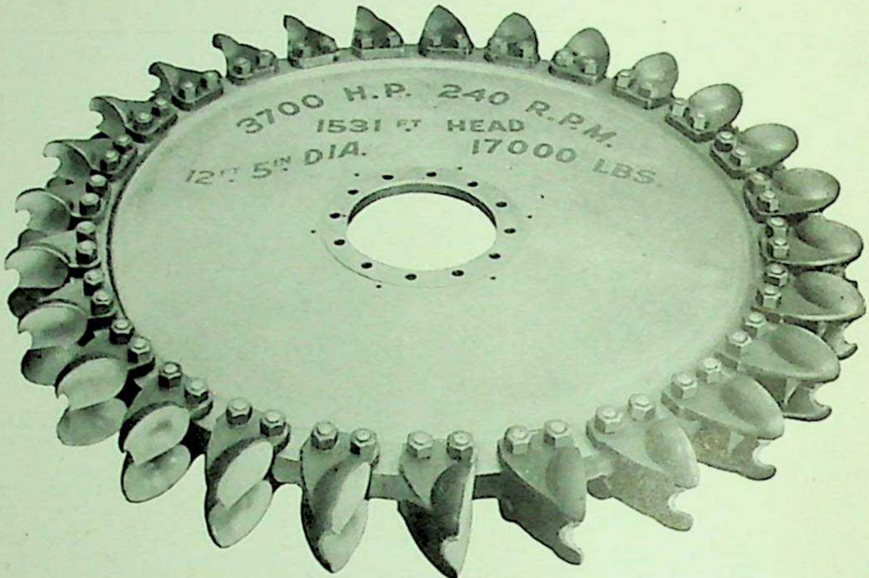

Fig. 6.

RUNNER OF 3700-HORSE-POWER WATER WHEEL
IN DE SABLA POWER PLANT

Figs. 6, 7 and 8 show types of Doble Tangential Water Wheels installed in the de Sabla Power Plant of the California Gas and Electric Corporation. This plant is a striking example of western power development, and embodies the most advanced features of engineering. The power house contains three two-bearing hydro-electric generating units—two of 3,700 horse-power and one of 8,000 horse-power capacity. A fourth unit, of 9,000 horse-power capacity, is now being installed.

Fig. 6 illustrates one of the 3,700-horse-power wheels, which operates under a head of 1,528 feet, driving a 2,000-kilowatt generator. The wheel-body is a nickel-steel forging, finished all over, and is bolted to the flanged end of the nickel-steel hollow-forged generator shaft. The buckets are open-hearth steel castings. The runner is 12 feet 5 inches in diameter, and weighs, complete with buckets, 17,000 pounds. The wheel has a speed of 240 revolutions per minute.

The wheel shown in Figs. 7 and 8 drives a 5,000-kilowatt generator which has regularly delivered 5,570 kilowatts on continuous load. This Doble Wheel is remarkable because of its high speed, i. e., 400 revolutions per minute, and

NEEDLE REGULATING NOZZLE

Regulation and conservation of water supply are important features of modern power plant practice. A plant may be arranged so as to be economically carried over the peak load by installing a Doble Needle Regulating Nozzle (Patented) and providing a moderate size storage reservoir at the head of the pressure pipe. Water may thus be accumulated in the reservoir during low-load periods, and become available for power when the station is called upon to carry a peak load.

Another economic advantage of the Doble Needle Regulating Nozzle is that it may be arranged to utilize the total power of the water where the supply is variable throughout the day, as may be the case where the water is drawn from snow fields, or where evaporation is excessive. By installing wheels and nozzles of sufficient capacity to carry the full overload on the generators, and by using a suitable governor on the nozzle, the water required for the wheels under variable load will be almost proportional to the power developed by the generators and delivered to the transmission lines, thus developing an ideal and uniform efficiency under a variable load.

While the Doble Needle Regulating Nozzle permits close regulation of speed, it also maintains a high efficiency of the jet over a wide range of discharge. As a result of the correct principles embodied in the design, the nozzle projects a solid cylindrical jet of high efficiency, free of any splash, spray, or rotating action. Investigations of this type of nozzle, made at the Massachusetts Institute of Technology in Boston, determined an efficiency as high as 99.3 per cent.

The regulating is done by moving an axial core—the needle—in a longitudinal direction within the nozzle, thus changing the annular area of the orifice and the quantity of water discharged. The regulating needle is machined all over, the bulb and point being finished to template and polished. The nozzle tip is a detachable piece, machined all over, the inner or hydraulic surface being finished to template and polished.

Fig. 11 shows a jet of water issuing from a three-inch Doble Needle Regulating Nozzle at the Snoqualmie Falls Power Plant near Seattle, Wash. The photograph was taken by flashlight, through an opening in the housing; the blur on the right is caused by the revolving buckets and wheel rim. When the photograph was taken the jet was reduced to two and one-fourth inches diameter.

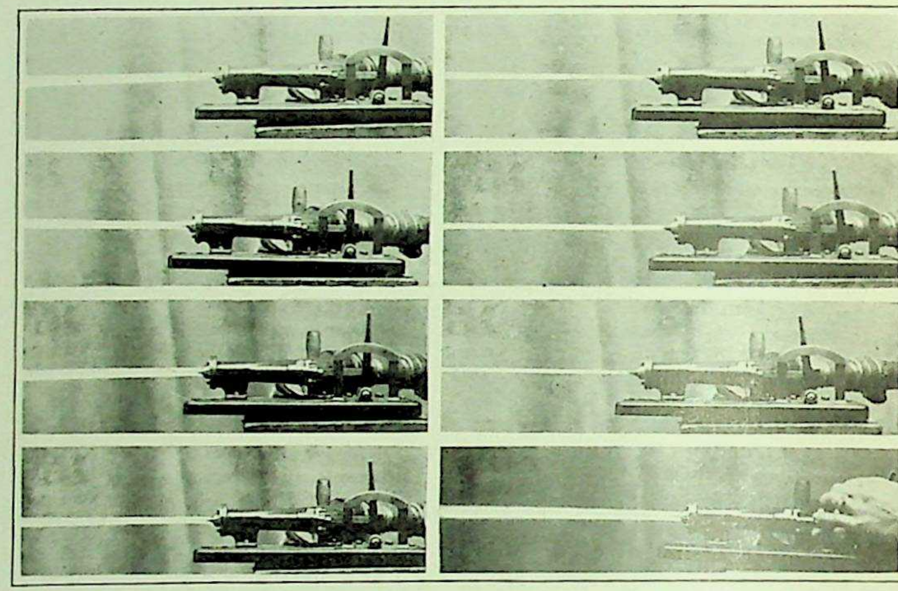

Fig. 12.

VARIOUS SIZED JETS FROM SMALL DOBLE NEEDLE REGULATING NOZZLE

Fig. 12 shows a small Needle Regulating Nozzle, under 55 pounds pressure, with the needle in eight different positions. The jet areas range from one-tenth to 25 per cent in excess of the full capacity of the normal opening. The jet is equally perfect in every instance, free of any spray, splash, or rotating action, such as would be detrimental to the efficiency of the jet, and which generally occur with plain nozzles without regulating needles.

The regulating needle of the Doble Nozzle may be arranged for operation by hand or by direct connection to an automatic governor.

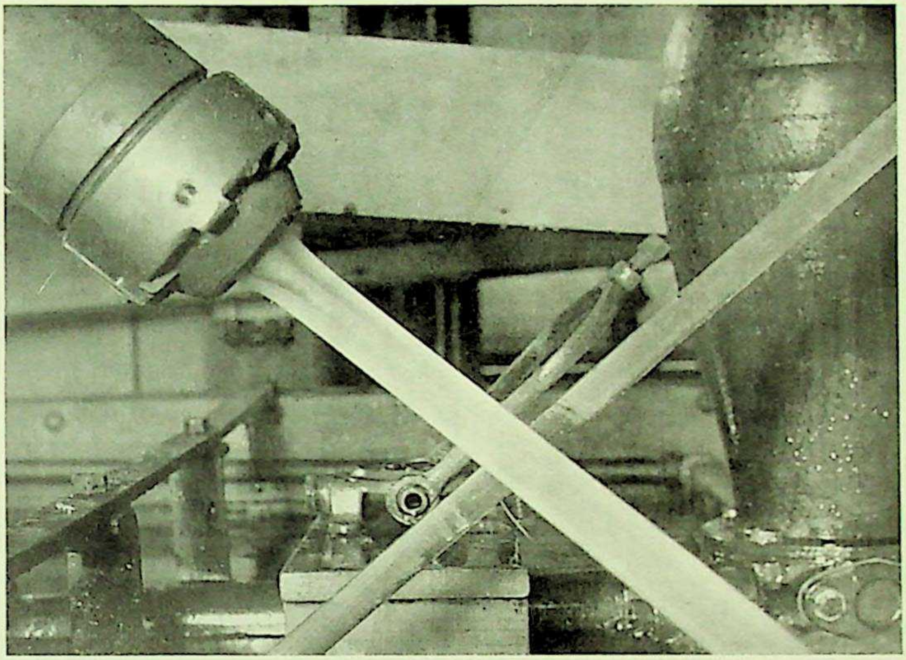

Fig. 13.

DOBLE NEEDLE REGULATING NOZZLE UNDER TEST. NOZZLE WIDE OPEN.

AN INVESTIGATION OF THE DOBLE NEEDLE REGULATING NOZZLE*

"The Abner Doble Company has for some years been studying nozzles to be used under high heads for power purposes, and, as a result of their investigations, have brought forth quite recently a needle regulating nozzle.

"For purposes of determining the efficiency of this nozzle, the Massachusetts Institute of Technology procured one of them.

"The nozzle (shown in Fig. 13) is similar to those now in use in connection with tangential water wheels in many large power plants on the Pacific Coast.

"Viewing the stream of water as it issues from the 'Doble' nozzle, one's attention is at once called to the clear, transparent, polished stream, the clean, glassy surface, and the absence of spraying in the proximity of the tip.

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*Abstract from thesi by H. C. Crowell and G. C. D. Lenth, Massachusetts Institute of Technology, Boston, June, 1903. The complete thesis is printed for gratuitous distribution in Bulletin No. 6, by the Abner Doble Company.

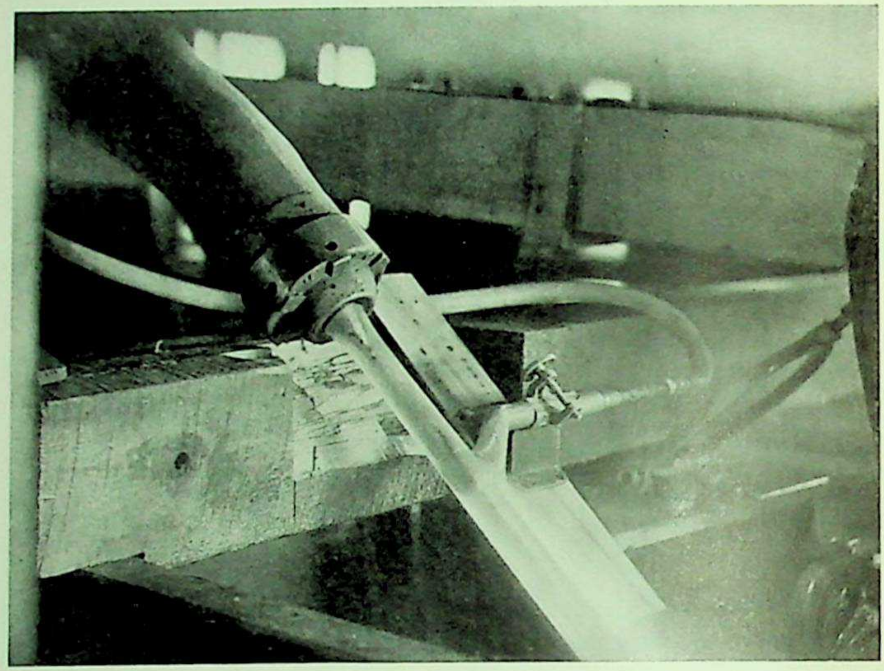

Fig. 14.

DOBLE NEEDLE REGULATING NOZZLE UNDER TEST.
MEASURING VELOCITY WITH PITOT TUBE.

"A general view of the special Pitot's tube used in the tests is shown in operation in Fig. 14.

"Remarkable symmetry of the velocity curve was found whenever a complete traverse of the stream was made.

"The most significant feature of all the velocity curves of the 'Doble' nozzle is the fact that the maximum velocity of the stream occurs within a few hundredths of an inch from the edge. This is a condition in streams from no other nozzle except the ring nozzle. Another surprising feature is the high velocity existing in the center of the jet from the 'Doble' nozzle, even within a half-inch from the needle. * * * The velocity in the center at this distance is 70 per cent of the maximum velocity. * * * At nine and one-half inches from the needle, the center velocity is over 96 per cent of the

NEEDLE REGULATING AND DEFLECTING NOZZLE

The local conditions governing the installation of certain water-wheel plants require the adoption of deflecting nozzles, either of the needle-regulating or the plain type. By the adoption of the Doble Needle Regulating and Deflecting Nozzle (Patented) the regulation of the power demanded from the wheel is accomplished by deflecting a portion, or the whole, of the jet from the buckets to the tailrace, as well as by varying the size of the jet by means of the needle.

The Doble Needle Regulating and Deflecting Nozzle shown in Fig. 16 projects a stream which develops 8,000 horse-power under a head of 1,250 feet. The nozzle body consists of two principal parts—one stationary, the other swinging on a pair of trunnions. The governor is connected to the deflecting element of the nozzle, and, as the load fluctuates, the stream is deflected away from, or onto, the buckets of the wheel, according as the load decreases or increases. The needle is operated by a hand wheel and spindle, thus taking care of the average variations in load, and permitting the greatest economy in the use of the water.

This type of nozzle may be used in a station supplying power to an electric railway with but few car equipments, and one that also furnishes a lighting load. By means of a deflecting nozzle a very large proportion of the entire power output of the station may be suddenly thrown on or off the plant, and still maintain a steady lighting load.

The Deflecting Nozzle is also a valuable device where riparian water rights on a stream have to be considered. For example, if the law requires that the natural flow of a stream must not be interfered with, the power plant is prevented from storing up the water which is not required during periods of low load and which would become available for periods of peak load. In such cases a deflecting nozzle permits of suitable load governing without interfering with the quantity of water used.

The Needle Regulating and Deflecting Nozzle is also of great value where the daily flow of the stream is subject to a wide variation, as it permits the power company to set the discharge orifice of the nozzle so as to use to the best advantage the total available flow as it varies throughout the day.

In cases where the pipe line is of great length, as, for example, between 5,000 and 10,000 feet, where momentary changes in the rate of flow set up serious disturbances in the pipe line, the Doble Needle Regulating and Deflecting Nozzle is particularly of great service.

Of the plants in which this type of nozzle has been installed, may be mentioned the Mill Creek No. 3 Plant of the Edison Electric Company, Los Angeles, and the de Sabla and Electra Plants of the California Gas and Electric Corporation, described respectively on pages 49, 53 and 58.

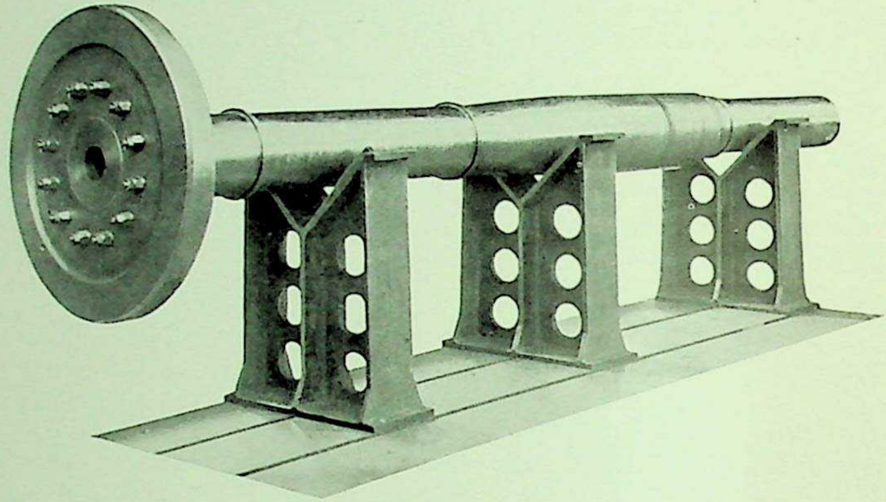

Fig. 17.

NICKEL-STEEL WATER-WHEEL SHAFT AND DISK FOR 8000-HORSE-POWER UNIT

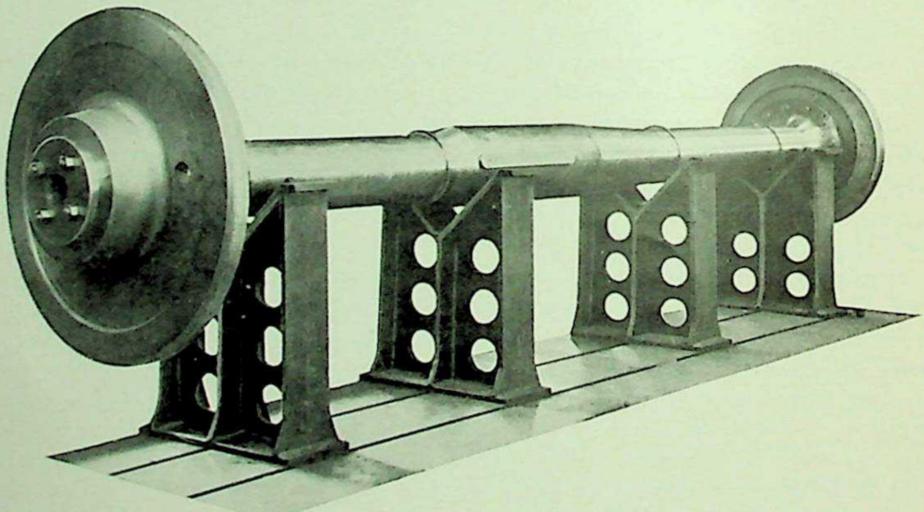

Fig. 18.

NICKEL-STEEL WATER-WHEEL SHAFT AND DISKS FOR DOUBLE UNIT. EACH WHEEL OF 8000 HORSE-POWER

SHAFTS

The forgings used for the shafts of Doble Water Wheels are made of special high-carbon open-hearth steel, rough-machined all over and carefully annealed. After annealing they are accurately machined to gauge, and the bearing surfaces are polished. In case of a hydro-electric unit, the shaft is extended so as to carry the revolving element of the generator.

For large water wheels, the shafts are made from fluid-compressed, 3½ per cent nickel steel. These shafts are hollow-forged under a hydraulic press, are rough-machined all over, and are then oil-hardened and tempered. The oil-tempered and annealed forging is then accurately machine-finished to gauge, and the bearing surfaces polished. As a rule, the hub for the water-wheel disk is forged with the shaft, in the form of a large flange, from a single ingot of steel.

Fig. 17 illustrates a shaft of this type, manufactured for an 8,000-horse-power hydro-electric unit for operation under a head of 1,250 feet. The shaft is 21 feet 5 inches long and is 20 inches in diameter at the center. The two bearings are each 16 inches in diameter and 5 feet long. The flange for the wheel hub is 33 inches in diameter, and is fastened by means of twelve taper nickel-steel coupling bolts to the forged disk. This disk is forged from medium-carbon open-hearth steel, and, after being annealed is finish-machined complete, and accurately fitted to the forged end of the shaft, as shown. The weight of this shaft is 19,018 pounds.

In Fig. 18 is illustrated a nickel-steel shaft, built for a Doble hydro-electric unit composed of two 8,000-horse-power Doble Water Wheels with an electric generator mounted between the wheels. This shaft is 24 feet 7 inches long, and has the same bearing dimensions as the single shaft shown above. One end of the shaft is fitted with a forged disk similar to that on the single shaft, for operation under a 1,250-foot head, while at the other end is fitted a medium-carbon open-hearth cast-steel wheel center, for operation under a head of 1,465 feet. This disk is carefully annealed, bored, key-seated, and fitted, being held on the end of the shaft by a flange secured by four studs. This 16,000-horse-power water-wheel shaft weighs 26,366 pounds.

The specifications for the two shafts stipulated that they show a tensile strength of not less than 90,000 pounds per square inch, and an elastic limit of 60,000 pounds per square inch. Upon test conducted in accordance with the specifications of the United States Navy, the shafts showed the following physical properties: Tensile strength, over 101,000 pounds; elastic limit, over 67,000 pounds; elongation, 23 per cent in 8 inches; reduction of area, 51.5 per cent.

Both shafts were manufactured by the Bethlehem Steel Company for its Pacific Coast Branch, the Abner Doble Company.

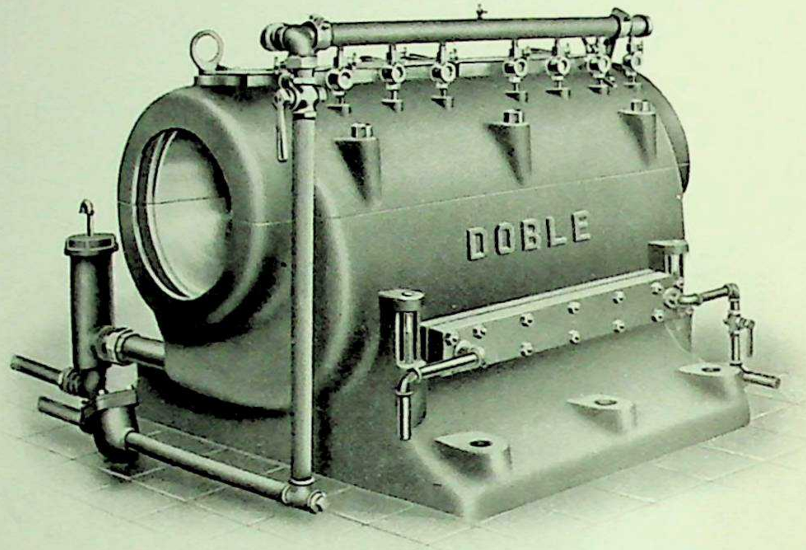

Fig. 19.
DOBLE RING-OILING, REVOLVABLE-SHELL BEARING

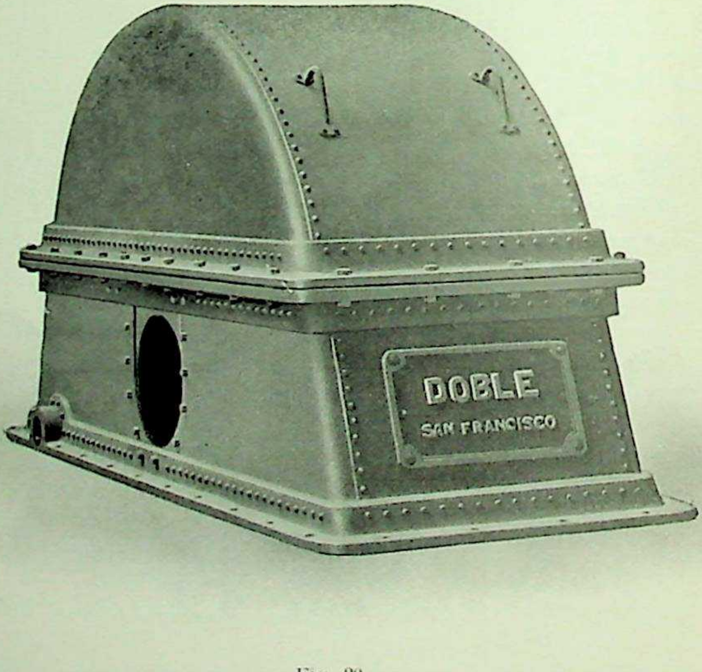

Fig. 20.
DOBLE WATER-WHEEL HOUSING

BEARING

Fig. 19 illustrates one type of our high-grade, ring-oiling, revolvable-shell bearings, for heavy duty. A typical feature of this Doble Bearing is that the lower shell may be taken out for inspection or scraping without removing the shaft. For that purpose rack teeth are provided on the outside of the shell. After the shaft is properly jacked up, the bottom shell may be revolved around it by means of crowbars working into the rack teeth.

The bearing shells are lined with genuine babbitt. The oil rings are made in halves so that they may be removed without disturbing the shaft and bearing shells.

The pedestal of the bearing forms an ample oil receptacle, and is provided with gauge glasses and drain cocks. To keep the oil cool, a system of tubes for circulating water is provided in the oil receptacle.

The bearing illustrated in Fig. 19 was built for a 9,000-horse-power unit, operating at a speed of 400 revolutions per minute. Its shaft diameter is 16 inches, and its length 60 inches. The rubbing speed in this bearing is higher than has been used heretofore.

HOUSING

Fig. 20 illustrates one of our types of water-wheel housings. It is an example of first-class boiler construction, all seams being hot-riveted and caulked.

The heavy cast-iron frames are machined at joining surfaces, and the bottom frame is faced where it rests on a cast-iron base frame.

CENTRIFUGAL WATER GUARD

One of the typical features of all Doble Water Wheels is our Centrifugal Water Guard (Patented), which is provided where the shaft enters the housing. These water guards, besides providing ample ventilation, prevent splash water from escaping the housing, thus serving the same purposes as stuffing boxes or packing glands without their objectionable feature, friction, to reduce the efficiency of the wheel.

The Doble Centrifugal Water Guard consist of two elements as indicated in Fig. 21. The revolving disk is fastened to the shaft, and revolves with it, and the stationary disk is bolted to the housing. The edges of the two elements overlap each other, forming an ample air space between them, through which air is drawn from the air inlet between the shaft and the stationary disk. The form of this device is such that water running down the side of the housing will flow around the stationary disk, while the revolving element throws off any water that may fall on it, thus preventing water from creeping along the shaft.

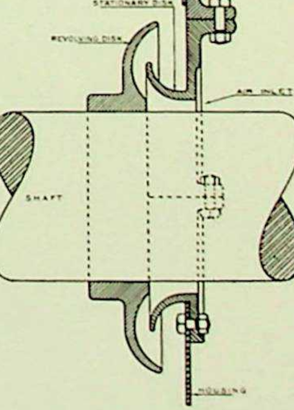

Fig. 21. DOBLE CENTRIFUGAL WATER GUARD

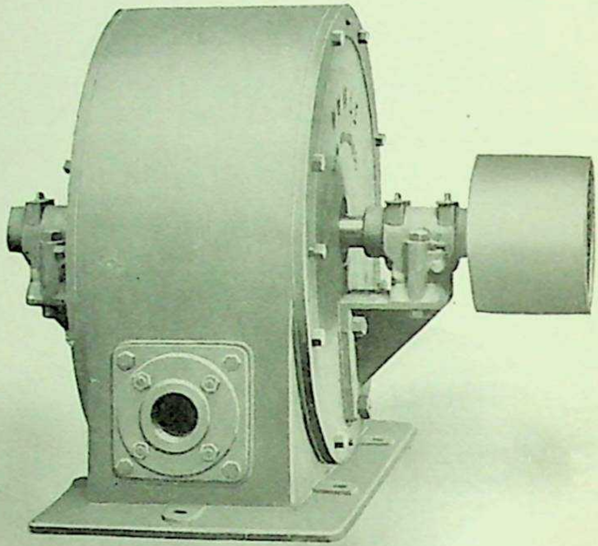

Fig. 22. WATER MOTOR FOR SMALL SIZES

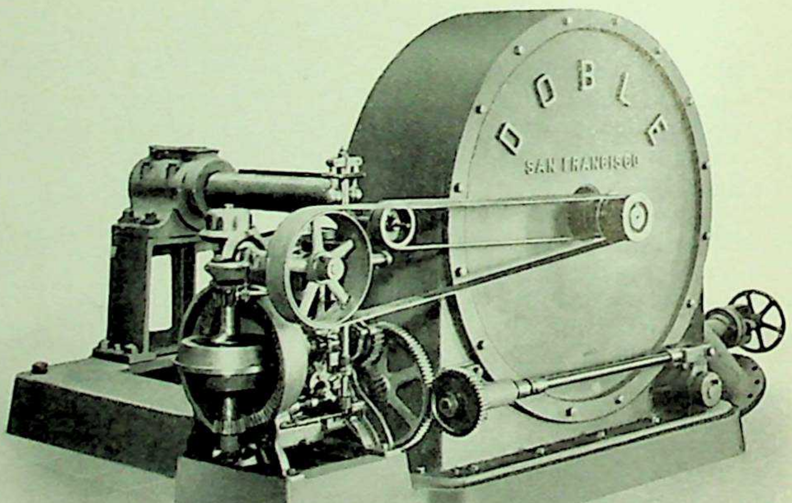

Fig. 23. BELTED TYPE OF WATER WHEEL WITH JET DEFLECTOR OPERATED BY MECHANICAL GOVERNOR

WATER MOTOR FOR SMALL SIZES

Fig. 22 illustrates our motor type of wheel. It is provided with a cast-iron housing having a cover on each side, these covers carrying the ring-oiling bearings on brackets. The pulley is overhung at one end of the shaft, and the housing is arranged in such a way that either a plain nozzle or a needle-regulating nozzle can be attached. The wheel shown in the illustration is provided with a plain nozzle, the companion flange being threaded for pipe connection. This motor is designed for low-pressure service and moderate power output.

BELTED TYPE OF WATER WHEEL WITH JET DEFLECTOR OPERATED BY GOVERNOR

The machine shown in Fig. 23 is a two-bearing unit with belt drive. It is provided with a Doble Needle Regulating Nozzle for hand control, and is also arranged for a stream deflector to be operated by an automatic governor. This deflector is located in front of the nozzle tip, on the inside of the housing. In case of partial or no load, the governor swings the deflector, by means of the rock shaft shown at the right, and thus intersects the stream before it reaches the buckets, deflecting it into the tailrace. The bearings, with their standards, and the water-wheel housing are mounted on a single substantial cast-iron bed-plate, thus making the entire machine self-contained and especially fitted for export purposes. The wheel shown in Fig. 23 is equipped with a Woodward compensating-type governor.

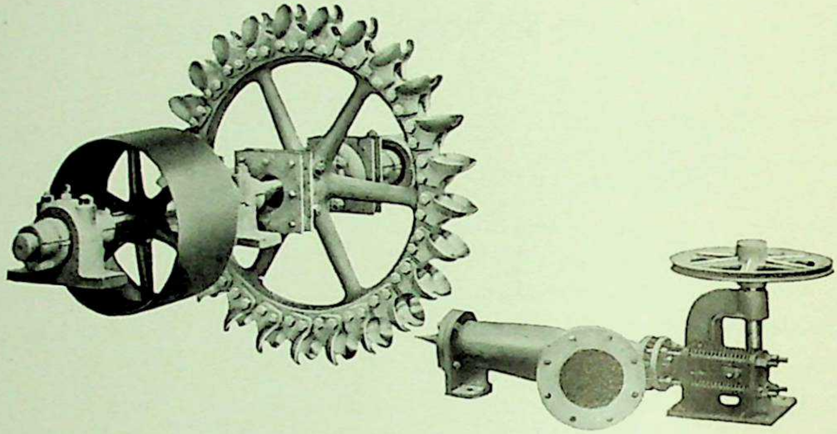

Fig. 24

BELTED WHEEL WITH REGULATING NOZZLE
OPERATED BY ROPE DRIVE

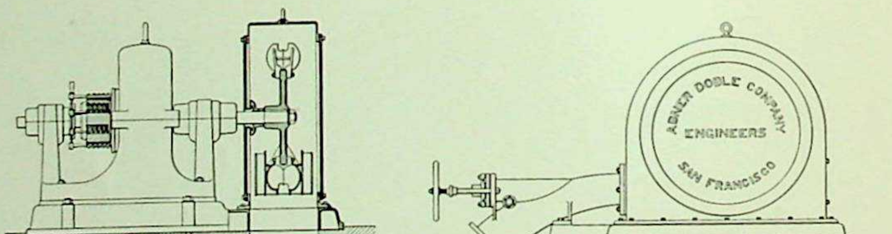

Fig. 25.

DIRECT-CONNECTED HYDRO-ELECTRIC UNIT

BELTED WHEEL WITH REGULATING NOZZLE OPERATED FROM A DISTANCE

In many instances, such as mining installations, the water wheel has to be placed where its immediate control by hand would be inconvenient. For such cases, the needle of the regulating nozzle may be arranged for operation from a distance by means of a suitable rope drive. Such an arrangement is illustrated in Fig. 24. Back of the nozzle there is provided a cast-iron stand with a vertical shaft, this shaft being connected to the regulating needle by means of a lever and links. The shaft carries a rope sheave, which, in connection with the rope drive, offers a convenient method for operating the needle from any desired point.

The wheel is equipped with Doble Ellipsoidal Buckets and the shaft is mounted in three ring-oiling bearings. The outfit, as illustrated, is ready for the foundation.

DIRECT-CONNECTED HYDRO-ELECTRIC UNIT

Fig. 25 shows a typical, direct-connected, hydro-electric unit provided with needle regulating nozzle for hand control. In many instances the conditions are such that the wheel may be carried on the extended shaft of the generator, as shown in the illustration. In the particular case illustrated, the generator is very conveniently placed on the same bed frame as the water-wheel housing, so that the unit is entirely self-contained. This bed frame is also extended to furnish a support for the nozzle, which is bolted against the side of the housing.

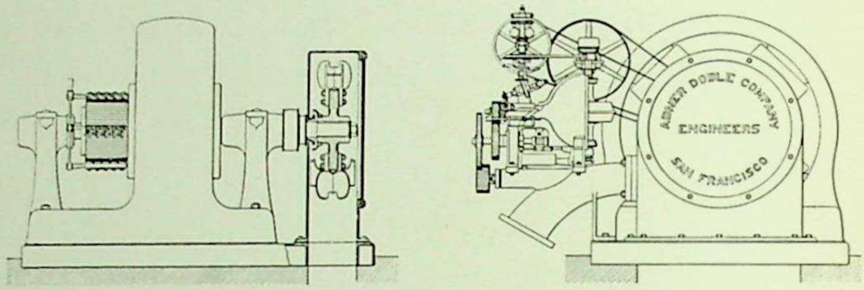

Fig. 26.

HYDRO-ELECTRIC UNIT WITH NEEDLE NOZZLE
OPERATED BY WOODWARD GOVERNOR

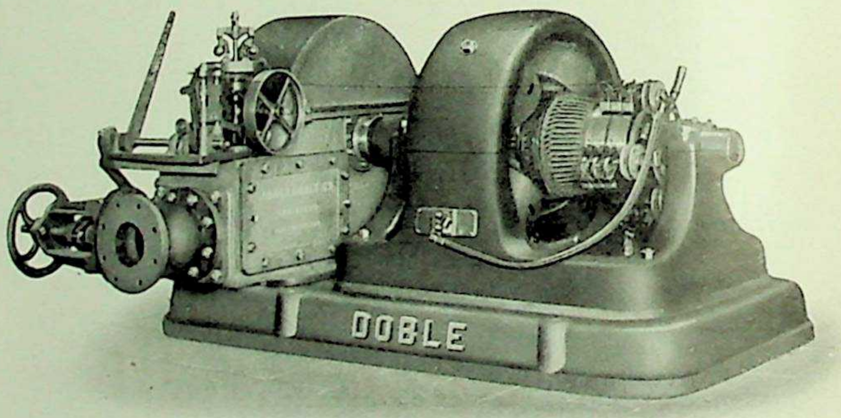

Fig. 27.

HYDRO-ELECTRIC UNIT WITH DEFLECTING NOZZLE
OPERATED BY REPLOGLE GOVERNOR

HYDRO-ELECTRIC UNIT WITH NEEDLE NOZZLE OPERATED BY WOODWARD GOVERNOR

The hydro-electric unit shown in Fig. 26 is similar in its arrangement to that illustrated in Fig. 25. Instead of having a needle nozzle arranged for hand control, however, the needle is directly operated by a Woodward compensating governor, which is mounted directly upon the nozzle body, and geared to the needle shaft. The needle shaft is threaded, and moves in a nut which forms a part of the nozzle body, so that the action of the governor regulates the position of the needle and the quantity of the water delivered, and thereby the output of the machine.

A wheel arranged with stream deflector, operated by a Woodward compensating governor, is illustrated in Fig. 23, on page 30.

HYDRO-ELECTRIC UNIT WITH DEFLECTING NOZZLE OPERATED BY REPLOGLE GOVERNOR

Fig. 27 illustrates an arrangement similar to the one shown above, the nozzle, which is of the deflecting type, being operated by a Replogle governor, mounted on a bracket of the housing. The gate valve, which is also shown in the photograph, is bolted directly to the nozzle flange. Manhole covers are provided on both sides of the housing, so that easy access may be had to the nozzle. The top cover of the housing body is also removable, so that the wheel may be readily inspected.

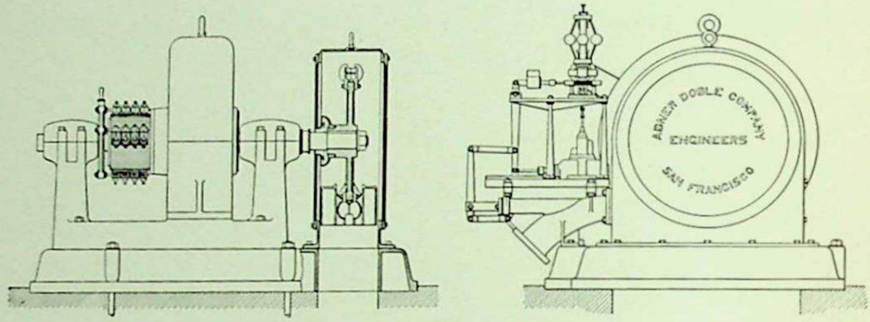

Fig. 28.

HYDRO-ELECTRIC UNIT WITH NEEDLE NOZZLE
OPERATED BY LOMBARD GOVERNOR

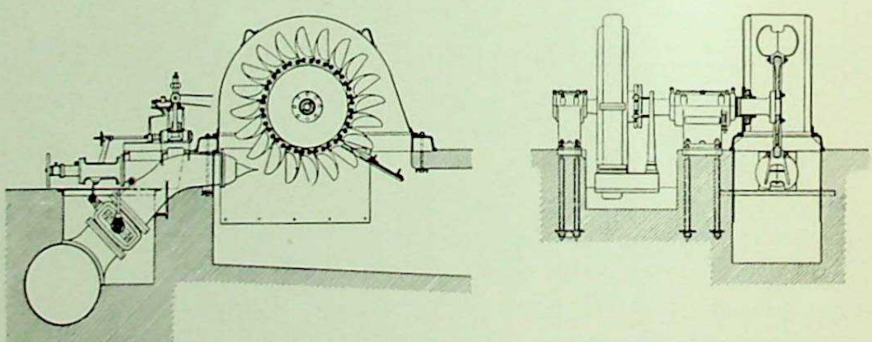

Fig. 29.

LOW-HEAD HYDRO-ELECTRIC UNIT WITH SPECIALLY DESIGNED GOVERNOR
OPERATING NEEDLE NOZZLE

HYDRO-ELECTRIC UNIT WITH NEEDLE NOZZLE OPERATED BY LOMBARD GOVERNOR

Fig. 28 shows a direct-connected hydro-electric unit, with needle regulating nozzle directly operated by a Lombard type J governor. This unit is also of the two-bearing construction, and illustrates the type of wheel for which we were awarded the Grand Prize at the St. Louis World's Fair in 1904.

LOW-HEAD HYDRO-ELECTRIC UNIT WITH SPECIALLY DESIGNED GOVERNOR OPERATING NEEDLE NOZZLE

A direct-connected two-bearing unit for a comparatively low head is shown in Fig. 29. In this case, the rotor of the engine-type generator is mounted on the water-wheel shaft. The bearings are of the ring-oiling type, and are independently mounted on sole plates, the latter being set in concrete piers, and held down by anchor bolts. The water-wheel housing has an independent base frame imbedded in concrete. The nozzle is of the needle regulating type, and is arranged for governor control in such a way that the governor may be easily disconnected, and the needle operated by hand. The governor is a specially designed Lombard governor, with a stroke-limit attachment, and is mounted directly upon brackets of the nozzle body.

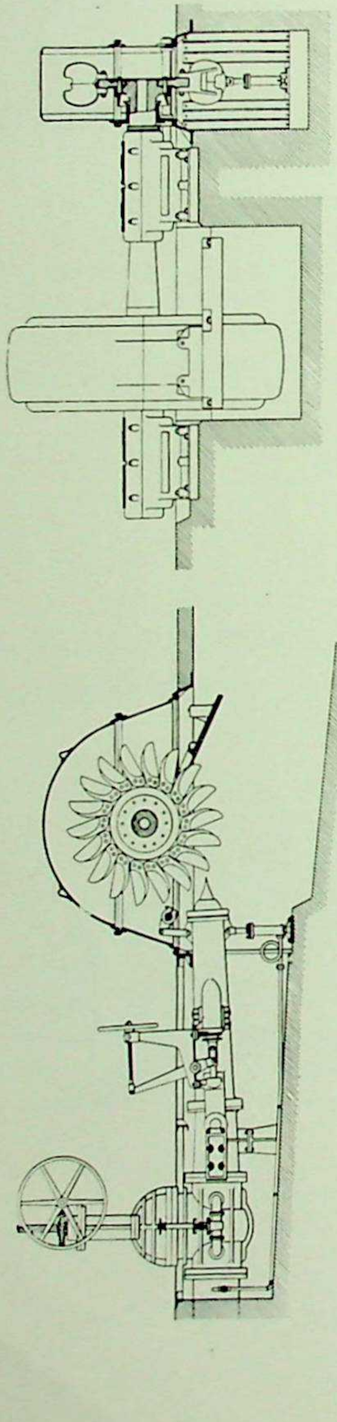

Fig. 30. TYPE OF LARGE HYDRO-ELECTRIC UNIT

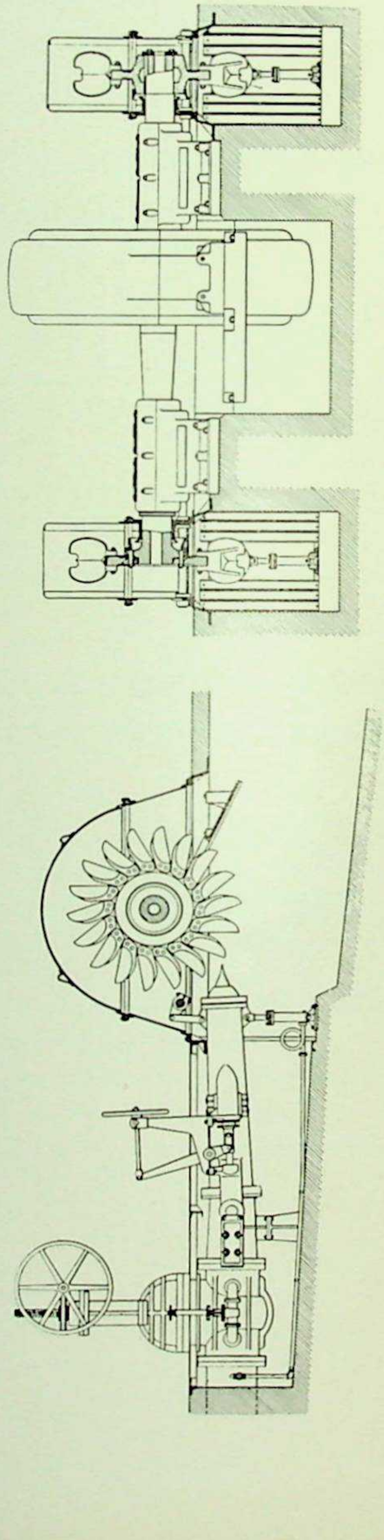

Fig. 31. DOUBLE HYDRO-ELECTRIC UNIT FOR LARGE CAPACITIES. TWO 8000-HORSE-POWER WATER WHEELS ON ONE SHAFT

LARGE HYDRO-ELECTRIC UNIT

Fig. 30 illustrates the design of a large unit, with needle regulating and deflecting nozzle. The machine is of the two-bearing type. The shaft is a hollow nickel-steel forging with a flange forged on at the end, against which the forged steel disk is bolted. The nozzle, ball joint, and buckets are steel castings, the ball joint being directly bolted against the main gate valve. The deflecting end of the nozzle is supported by a hydraulic balancing cylinder (patent pending). The needle is operated by hand, the deflecting mechanism of the nozzle being operated by a Lombard governor. The governor rock shaft is shown in the illustration above the nozzle tip. We have built water wheels of 8,000 and 9,000 horse-power capacity of this type.

DOUBLE HYDRO-ELECTRIC UNIT FOR LARGE CAPACITIES

Fig. 31 in its general design is similar to that shown in Fig. 30, being a two-bearing unit, with the water applied to the wheels through needle regulating and deflecting nozzles. There is, however, a water wheel attached to each end of the shaft, the two wheels being designed to work under two different heads, so that the generator can be operated from either one of the pipe lines, or the load can, by means of the regulating needles, be divided between the two pipe lines in any desired proportion, depending upon the prevailing hydraulic conditions. A double unit of this type, consisting of two 8,000-horse-power wheels connected to a 5,000-kilowatt generator, has been built by us for the Electra Power House of the California Gas and Electric Corporation.

LABORATORY WATER MOTOR

Fig 32 shows a 12-inch Doble Water Motor designed especially for laboratory use, which we build for universities and technical colleges. This small machine is self-contained, and has the shaft extended far enough to carry a pulley or prony brake. The motor is provided with a Doble Needle Regulating Nozzle for hand

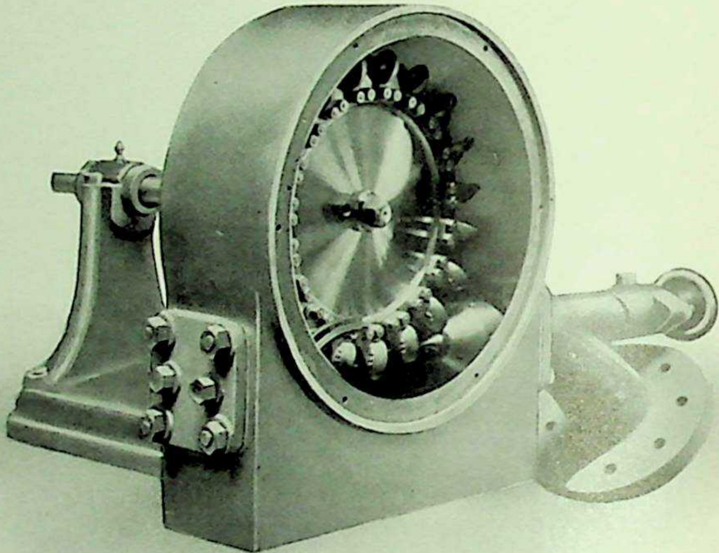

Fig. 32.

LABORATORY WATER MOTOR FOR TECHNICAL COLLEGES

control, so that the jet of water may be varied to give the desired regulation in speed. The housing has plate-glass sides in order that the students may easily observe the water acting on, and discharging from, the buckets.

These little machines embody the best workmanship that can be turned out, and are designed and finished exactly upon the same lines as our largest machines, the buckets being formed of independent gun-metal castings, ground and polished on the hydraulic surfaces, and bolted to the wheel disc, each by two body-bound bolts fitted into reamed holes.

The motors are designed and constructed so as to operate under heads up to 1,000 feet, and are therefore admirably suited for experimental use in a hydraulic laboratory under all pressures that are commonly available.

We have furnished laboratory wheels of this type to Columbia University, Polytechnic Institute of Brooklyn, University of Iowa, University of Missouri,

University of Illinois, University of Texas, Michigan School of Mines, University of Wisconsin, University of Toronto, University of Colorado, Lafayette College, and University of Pennsylvania. Parts of wheels for experimental purposes have been furnished to the University of Michigan and Massachusetts Institute of Technology. The University of Michigan has also purchased, as mentioned on page 9, our St. Louis World's Fair exhibit wheel for its hydraulic laboratory.

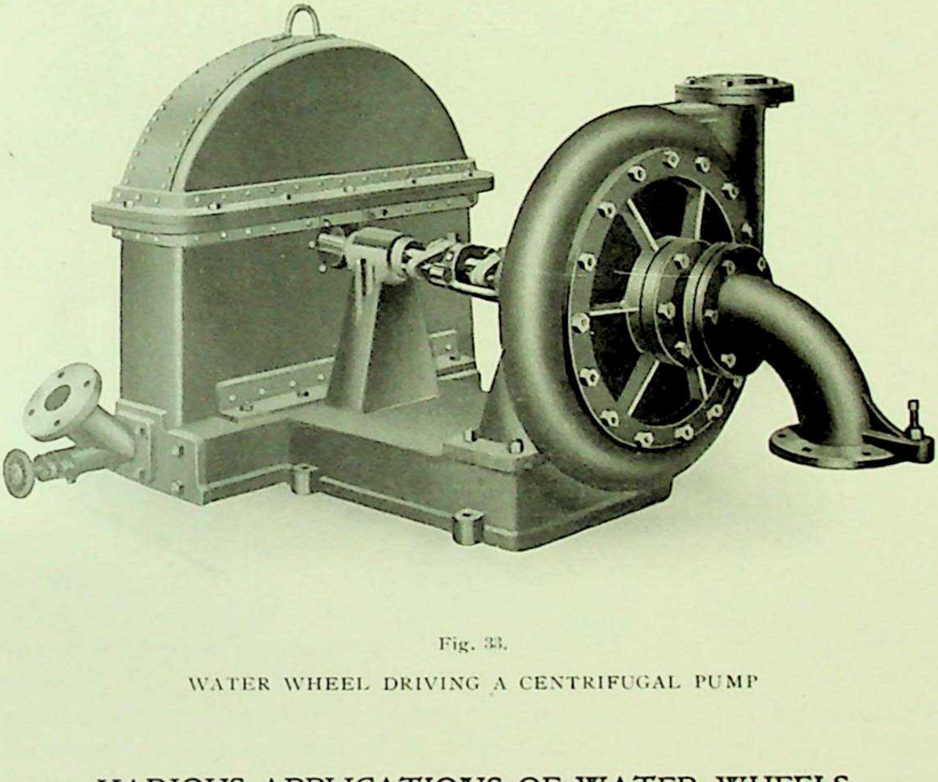

Fig. 33.

WATER WHEEL DRIVING A CENTRIFUGAL PUMP

VARIOUS APPLICATIONS OF WATER WHEELS

Doble Tangential Water Wheels may be applied for direct or belt connection to a great variety of high and low-speed machines, such as pumps, hoists, compressors, blowers, mining machinery, sawmills, etc.

In Fig. 33 is illustrated a centrifugal pump directly connected to a Doble Tangential Water Wheel. The wheel is operated by a jet of water projected from a Doble Needle Regulating Nozzle, arranged for hand control. In this case a comparatively small quantity of high-pressure water is utilized to lift a larger quantity of water against a comparatively low head.

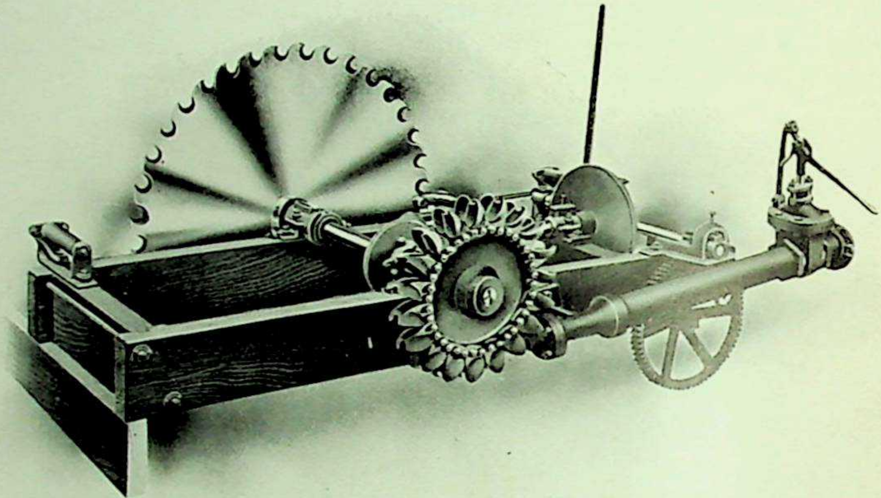

Fig. 34.

WATER WHEEL DRIVING SAW MILL

Fig. 34 shows a Doble Tangential Water Wheel as applied to the operation of a sawmill. As shown, the wheel is directly mounted on the mandrel of the circular saw of the mill. The water-wheel nozzle is bolted directly against the husk frame of the saw, and the pipe leads immediately into it. A quick-acting gate valve is located near the end of the frame, where the shipper lever of the friction feed of the sawmill is operated, so that one man can handle all operations of the mill without changing his position. This unique outfit, which is entirely self-contained, was shipped to the Philippine Islands, where it will do service in the rich timber district near Fidelesan.

We have built several sawmill units with needle regulating nozzles, adapted for hand control, an arrangement which we specially recommend.

SAFETY AIR VALVE FOR PIPE LINES

Figs. 35 and 36 illustrate a safety air valve as supplied for pipe lines. The purpose of this type of valve is to open automatically in case the pipe line should be emptied suddenly, and to permit the air to rush in, thus preventing the pipe from collapsing on account of the vacuum formed inside. These valves have to be inspected occasionally, and therefore it is advisable to provide the portable clamp and hand-wheel attachment shown in Fig. 35. By means of this hand-wheel the valve can be screwed down away from its seat when under pressure, thus permitting proper inspection and flushing.

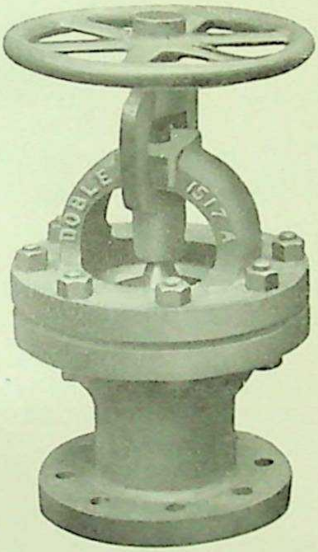

Fig. 35.

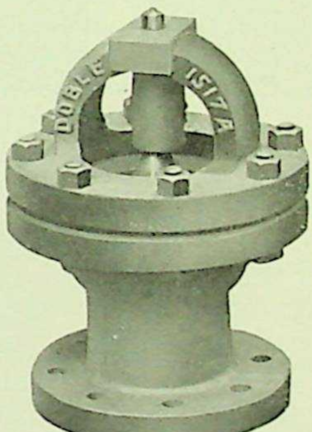

Fig. 36.

SAFETY AIR VALVE FOR PIPE LINES

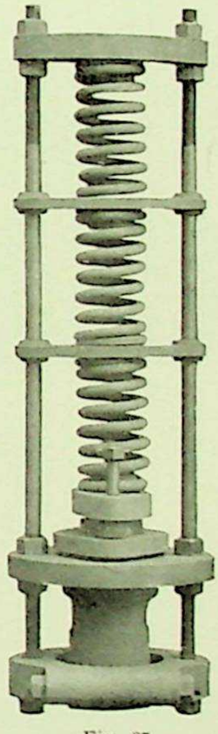

Fig. 37.

SPRING - BALANCED COMPENSATOR FOR PIPE LINES

SPRING-BALANCED COMPENSATOR FOR PIPE LINES

A spring-balanced compensator for pipe lines is illustrated in Fig. 37. This apparatus serves to take care of shocks in the pipe line which might be caused by sudden action of the governor, checking the flow of water, or by too rapid closing of a gate valve. It consists of a hydraulic plunger connected to the pipe line, and balanced by suitable steel springs. In case of an increase of pressure in the pipe line, the area at the particular point where the compensating plunger is located is increased, and the pressure relieved. Such compensators are very useful where an angle occurs in the pipe line.

Fig. 38.

JET FULL ON THE REVOLVING WATER WHEEL AND DEVELOPING 1000 HORSE-POWER

Fig. 39.

JET FULL ON THE VORTEX BAFFLE PLATE, 1000 HORSE-POWER BEING HARMLESSLY ABSORBED

VIEWS OF A TAIL RACE EQUIPPED WITH THE ENSIGN VORTEX BAFFLE PLATE

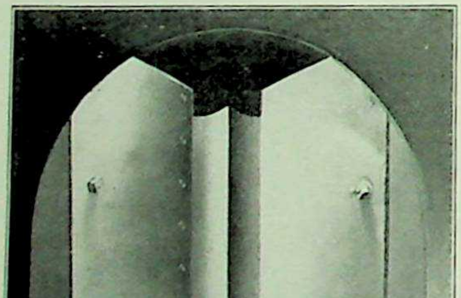

Fig. 40.

ENSIGN VORTEX BAFFLE PLATE AS INSTALLED IN A TAIL RACE

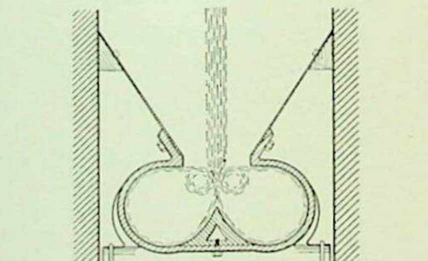

Fig. 41.

PLAN OF THE VORTEX BAFFLE PLATE, SHOWING THE THEORY OF ITS ACTION

ENSIGN VORTEX BAFFLE PLATE

In the case of long pressure pipes, especially when under high pressure, it is difficult and dangerous to suddenly vary the quantity of water delivered by the nozzle, in such a manner as is necessary to regulate the speed of a hydro-electric generating unit, subject to sudden violent variations of load.

Consequently it has become customary to regulate the speed of such units by deflecting the jet of water, so that all, or part, of it misses the water-wheel buckets, and is for the moment necessarily wasted.

The water, which is thus prevented from giving its energy to the water wheel, is projected through the tailrace at a very high velocity—in some cases exceeding 300 feet per second (18,000 feet per minute)—and becomes destructive. In most cases the water unavoidably carries infinitesimal particles of sand. No masonry can long withstand the action of such a jet, and even iron and steel are rapidly worn away, as if by a terrific sand blast.

The Ensign Vortex Baffle Plate (Patented), illustrated in Fig. 40, is designed to divide such a jet in halves, and deflect the halves until they impinge upon each other, and harmlessly spend their force. The device is a trough-like structure with a sharp central vertical dividing wedge, made to be replaceable in case of wear. The device splits the impinging jet, and guides each half around the curved surfaces, spreading it out into two thin sheets which meet and harmlessly spend their force against each other. The water then falls by gravity into the tailrace with no more disturbance than is shown in Fig. 39.

As shown in the plan Fig. 41 the device is to be firmly anchored in the tailrace. It may be fastened by means of stirrup bolts to heavy "I" beams set in the masonry, and should have a V-shaped entrance, as shown in the plan, to guide all the spray into the arrester.

This baffle plate has been in successful operation for several years in the Mill Creek No. 3 Power Plant of the Edison Electric Company, where the static head of water is 1,960 feet, the pressure over 850 pounds per square inch, and the spouting velocity over 350 feet per second (about 4 miles per minute). Fig. 38 illustrates the Mill Creek tailrace with the jet full on the wheel, and Fig. 39 similarly shows the tailrace with the jet full on the baffle plate.

In plants where the water must be carefully conserved for irrigation or power, as at Mill Creek No. 3, the Vortex Baffle Plate is desirable also as a water saver. Its influence is to eliminate the great clouds of fine spray which are noticeable over tailraces not equipped with the Vortex Baffle Plate, and from which excessive evaporation takes place, especially in dry climates, such as that of Southern California and Colorado.

If the power plant is to be tested, or in any case where the water issuing from the tailrace is to be accurately measured by means of a weir or measuring flume, the Vortex Baffle Plate is almost a necessity in order to quiet the water so that reliable results may be obtained.


GRAND · PRIZE
· LOVISIANA · PVRCHASE ·
· EXPOSITION ·


· GOLD · MEDAL ·
· LOVISIANA · PVRCHASE ·
· EXPOSITION ·


AWARDED BY THE CITY OF PHILADELPHIA


THE JOHN SCOTT MEDAL TO THE MOST DESERVING

THE GRAND PRIZE awarded by the Louisiana Purchase Exposition, 1904, to the Abner Doble Company, San Francisco, U. S. A., for its exhibit in the Department of Machinery of a Doble Tangential Water Wheel.

GOLD MEDAL awarded by the Louisiana Purchase Exposition, 1904, to William A. Doble, president of the Abner Doble Company, San Francisco, U. S. A., as a collaborator's award, "In recognition of his distinguished services in Hydraulic Engineering."

JOHN SCOTT LEGACY PREMIUM AND MEDAL awarded by the City of Philadelphia, trustee under the will of John Scott of Edinburgh, Scotland, to William A. Doble, president of the Abner Doble Company, San Francisco, U. S. A., "For his Improvements in the form of Buckets for Tangential Water Wheels, on the recommendation of the Franklin Institute, 1904."

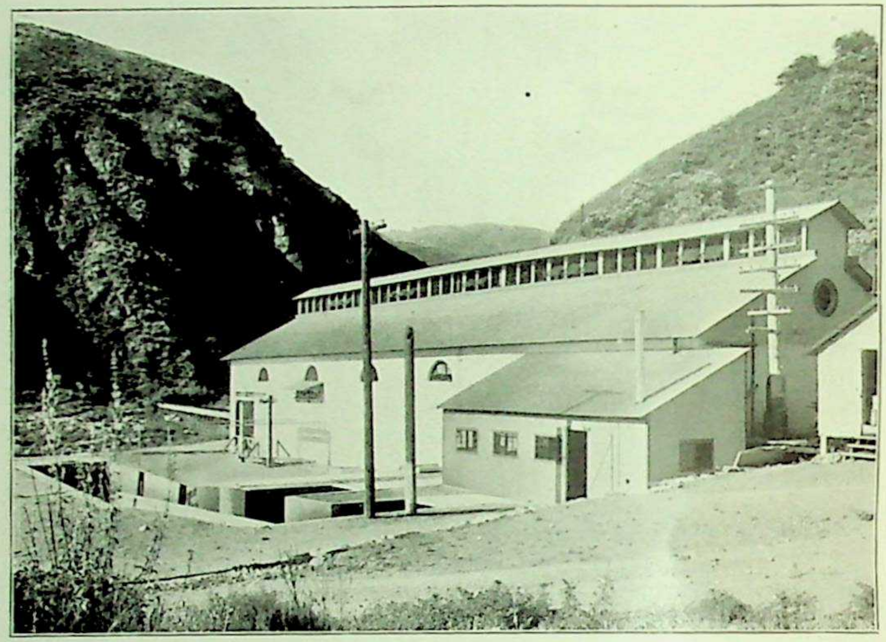

Fig. 42. MILL CREEK No. 3 POWER PLANT

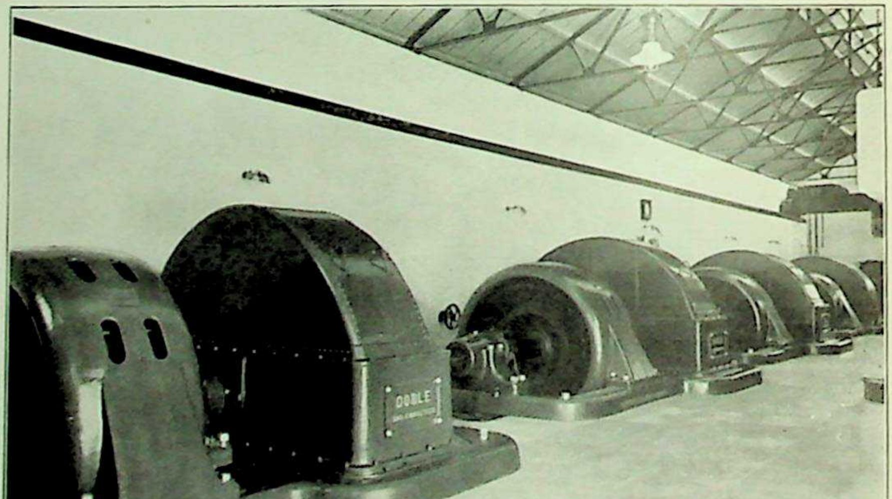

Fig. 43. MILL CREEK No. 3 POWER PLANT

MILL CREEK NO. 3 POWER PLANT

The Mill Creek No. 3 Power Plant of the Edison Electric Company, Los Angeles, Cal., went into service in March, 1903. It is remarkable for the high head used. All of the water usually flowing in Mill Creek at Akers Narrows is diverted by a masonry dam, and conducted through 5 miles of pipe to a petty reservoir 1,960 feet above the power house in Mill Creek Canyon. The conducting pipe slopes 0.2 feet per 100 feet, and is designed to carry 20 cubic feet of water per second. It contains 5 inverted siphons of steel pipe, aggregating 3,585 feet in length, and 25,190 feet of concrete pipe, 3 inches thick and 32 inches inside diameter, and passes through 10 tunnels having an aggregate length of 7,500 feet.

From the petty reservoir the water descends through a steel pressure pipe, varying in diameter from 26 to 24 inches, and in thickness from No. 14 B. W. G. to ⅞ inch. The lower portion of this pipe is lap-welded. The pipe is protected from rust by a heavy coat of asphaltum, applied by dipping. At the lower end it branches, leading the water through 18-inch and 14-inch lap-welded pipe to the four generating units, which are housed in a concrete building, with steel roof trusses and galvanized-iron roof. Of these generating units, three were made by the Abner Doble Company.

Each Doble unit consists of a 1,300-horse-power Doble Tangential Water Wheel and a 750-kilowatt, three-phase generator, mounted on a single shaft. This shaft has a speed of 430 revolutions per minute, and is mounted in three bearings which rest on a single cast-iron base frame, set in concrete. Each wheel is provided with a Doble Needle Regulating and Deflecting Nozzle, with hand-operated balanced needle. With this apparatus the station attendant can set the needle by hand every half hour at the most economical point, in order to carry the load which, from experience, he is led to expect during the next half hour. The governor takes care of all sudden fluctuations of load, by deflecting the nozzle momentarily, so that all or part of the water issuing passes under the water wheel and wastes its energy against the Vortex Baffle Plate (pages 44 and 45), installed in the tailrace.

The static pressure due to the head of 1,960 feet is over 850 pounds per square inch, and the spouting velocity of the jet is about 4 miles per minute. The nozzle and water wheel were carefully designed and constructed to meet these requirements. Not only were the hydraulic curves worked out to a high degree of refinement, but the machine work was executed and checked with equal care under the same painstaking supervision; the value of which is apparent after two years' operation.

The materials chosen for this unit were the best that could be found, regardless of cost. The needle stem is of forged marine steel. The nozzle is of semi-steel, and the wheel body is a steel casting. The buckets are of the well-known Doble Ellipsoidal form, and are interchangeable. They are fitted tightly to both the sides and edge of the wheel-body, and each is secured by two fitted bolts driven into reamed holes. Not a single bucket has yet had to be replaced, although the wheels have been operating continuously for over two years. The housing is of cast iron and plate steel, and is provided with Doble Centrifugal Water Guards.

The generating units deliver three-phase current at 750 volts to the switchboard, whence it passes through transformers, and out over the 33,000-volt 86-mile transmission line to Los Angeles.

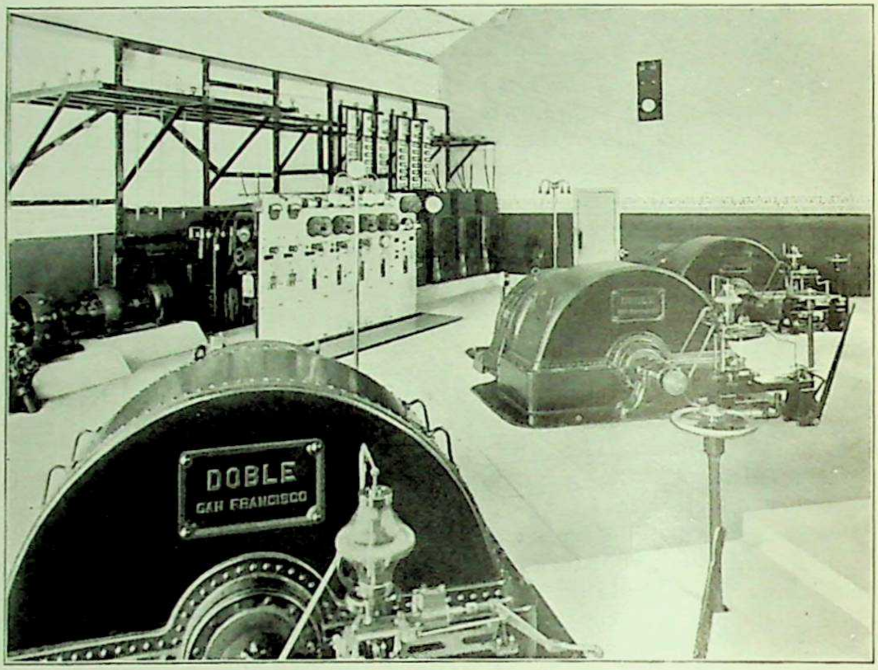

Fig. 44. ONTARIO POWER PLANT

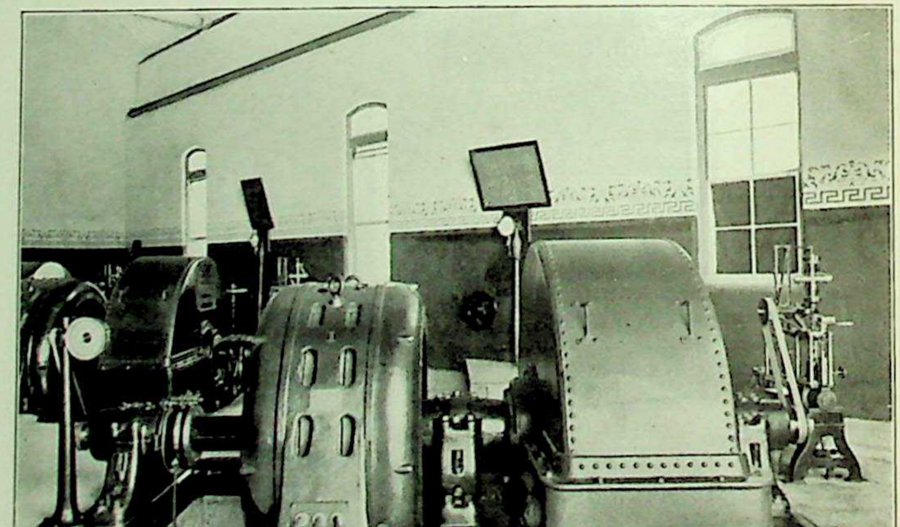

Fig. 45. ONTARIO POWER PLANT—DOBLE UNIT

ONTARIO POWER PLANT

A hydro-electric power plant which has attracted some little attention, by reason of the excellent engineering features embodied in its construction, is that of the Ontario Power Company in Southern California. This plant is a part of the extensive and well-developed irrigation system of the Ontario Colony, and in addition to supplying all the power for pumping and lighting, needed by the colony, furnishes considerable power to outside customers. It is located near the mouth of San Antonio Canyon, about 9 miles from Ontario, and a short distance below the historic Pomona Plant.

At the headworks water is received from the tailrace of the Sierra Power Plant; it is then carried through a 30-inch concrete-pipe gravity line along the west side of the canyon, and dropped through a riveted-steel and lap-welded pipe to the power house, situated 700 feet below.

The equipment of the power house comprises three hydro-electric units, each consisting of a 460-horse-power Doble Tangential Water Wheel direct-connected to a 250-kilowatt, three-phase, 50-cycle, 11,500-volt alternator. Each unit is of the three-bearing type, and has a speed of 375 revolutions per minute. The water wheels are equipped with Doble Needle Regulating and Deflecting Nozzles, the deflecting elements being controlled by hydraulic governors.

Two 28-horse-power Doble Tangential Water Wheels operate the exciters and are equipped with Doble Needle Regulating Nozzles, the needles being controlled by Woodward governors.

The wheels of the Ontario Plant have been operating almost continuously for nearly three years, and, although there has been considerable sand in the water, the hydraulic surfaces of the buckets are remarkably smooth, indicating that the wear has been even over the entire working face of the buckets. These wheels have frequently been called upon for operation under heavy overloads.

Tests conducted by Mr. F. E. Trask show an average combined efficiency of the three units of 77.7 per cent at the switchboard, the efficiency of the Doble Wheel being 83.6 per cent (Trans. A. S. C. E., April 15, 1905). In the test, from which these figures were obtained, the water used on the exciter wheels was charged up against the water wheel, as was also the power consumed by friction and windage of the generator. Proper allowance for these factors would give the true efficiency of the wheel, and, of course, increase the figure above that noted.

Fig. 46. DE SABLA POWER PLANT ON BUTTE CREEK

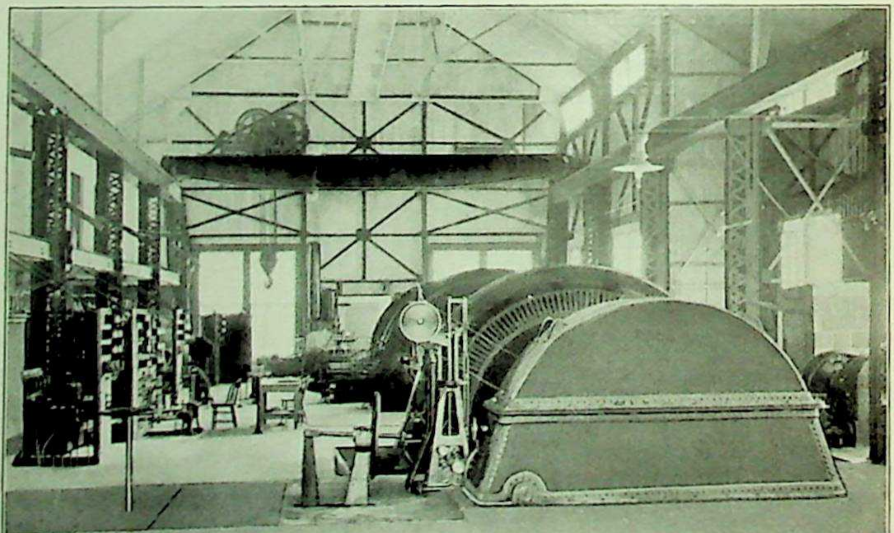

Fig. 47. INTERIOR OF DE SABLA POWER HOUSE

DE SABLA POWER PLANT

The de Sabla Power Plant in Butte County, California, embodies some of the most advanced ideas in hydro-electric power-plant practice. This plant was erected by the Valley Counties Power Company in 1903, and is now an important source of supply for the California Gas and Electric Corporation's extensive transmission system.

Water is taken from Butte Creek through a 12-mile ditch, and also from a branch of the Feather River, both conduits discharging into a regulating reservoir at the head of the pressure line. From this reservoir, two 30-inch steel pressure pipes, over 6,000 feet in length, conduct the water down to the power house, the total effective head being 1,528 feet. One pressure line supplies two 2,000-kilowatt hydro-electric units, and the second line supplies a 5,000-kilowatt unit. Hydraulically operated piston gate valves of a special design are installed in the branch pipes leading to the units.

Each of the 2,000-kilowatt units consists of an inductor-type, 60-cycle, three-phase, 2,300-volt alternator directly driven by a 3,700-horse-power Doble Tangential Water Wheel, the speed being 240 revolutions per minute. The 5,000-kilowatt alternator is of the revolving-field type, and is directly driven by an 8,000-horse-power Doble Tangential Water Wheel, the speed being 400 revolutions per minute.

All three units are of the two-bearing type, the water wheel being mounted on the extended end of the generator shaft and overhanging one bearing. Each water wheel is provided with a Doble Needle Regulating and Deflecting Nozzle.

The larger wheel was the most powerful single water wheel constructed at the time it was placed in operation, September, 1904. It delivers 8,000 horse-power from a single jet of water, the jet having a spouting velocity of approximately 20,000 feet per minute. The general design of this unit is shown in Fig. 30, on page 38. The shaft is of fluid-compressed, hydraulically forged, 3½ per cent nickel steel, oil-tempered and annealed, with an axial hole. It is 20 inches in diameter in the middle portion and 16 inches in the bearings, the latter being 60 inches long and of ring-oiling and water-cooled construction. These bearings have a higher rubbing speed than has been used heretofore, and their successful operation demonstrates the correctness of their design. The steel-cast Ellipsoidal Buckets are securely bolted to the periphery of a forged steel disk, which is machine-finished all over.

Regulation of this plant is secured by hydraulic governors, which deflect the nozzles as the load varies.

The transmission voltage is 55,000 volts, and current has been delivered from this plant, over the lines of the California Gas and Electric Corporation, a distance of 378 miles from the power house, the present record for long-distance transmission.

Considerable interest now centers in a new hydro-electric unit about to be installed in the de Sabla Plant, the hydraulic end of which will consist of a 9,000-horse-power Doble Tangential Water Wheel. This wheel will be driven by a single jet of water, and will embody the same general features of design as the 8,000-horse-power de Sabla wheel.

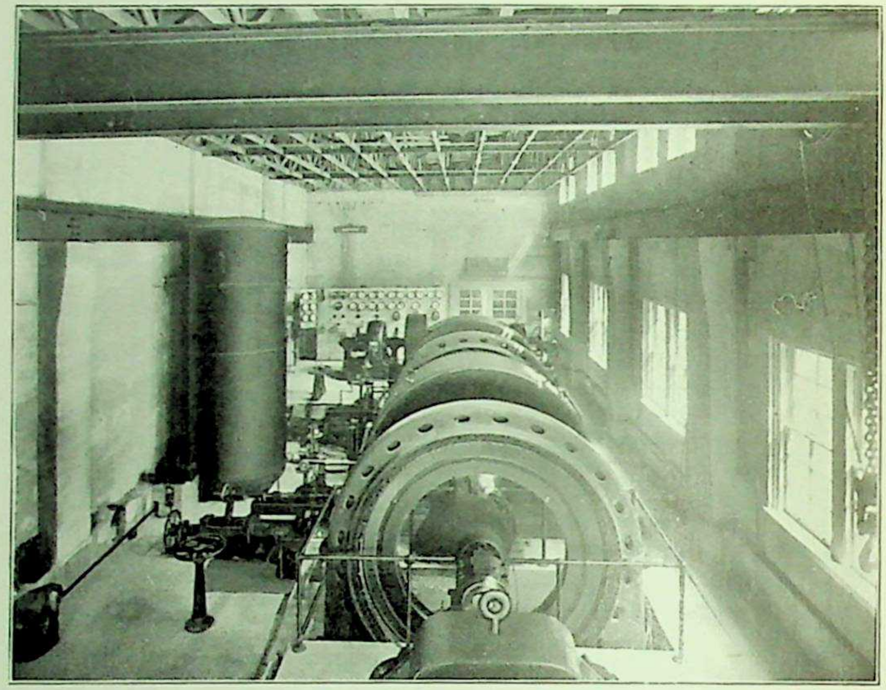

Fig. 48. CORNELL UNIVERSITY POWER PLANT

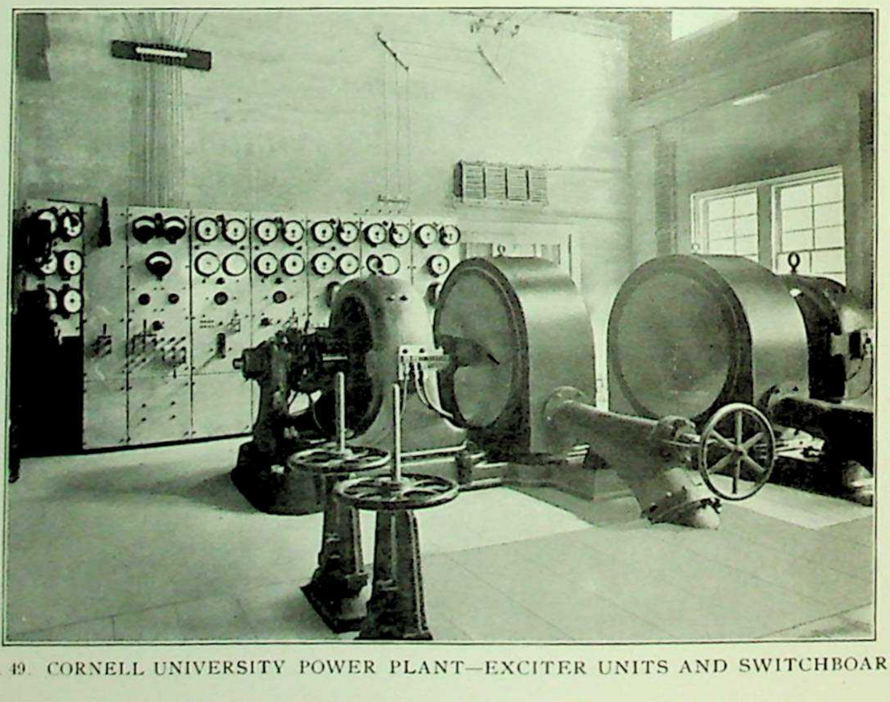

Fig. 49. CORNELL UNIVERSITY POWER PLANT—EXCITER UNITS AND SWITCHBOARD

CORNELL UNIVERSITY POWER PLANT

The new hydro-electric power plant of Cornell University, Ithaca, N. Y., possesses many points of engineering interest. It furnishes power for lighting, ventilating, and the operation of shops and laboratories, and thus forms a very valuable acquisition to the engineering equipment of the college. The plant is located in Fall Creek Gorge, on the University Campus, directly in the rear of Sibley College, where it replaces an old turbine plant.

The selection of the type and character of the main generating units was made with special regard to high efficiency at low water. As the head of 134 feet introduced a likelihood of very low average operating efficiency for turbines, especially at partial loads, and because of the trouble experienced from the original turbine installation, particularly during occurrence of ice, it was decided that the more expensive tangential type of wheel should be used.

Each of the two hydro-electric units installed consists of a 150-kilowatt, rotating-field, three-phase, 60-cycle, 2,200-volt generator, operated by a 280-horse-power Doble Tangential Water Wheel. The speed of rotation is 124 revolutions per minute, and the driving jet is 7 inches in diameter. The floor space occupied by each unit is 14 feet by 21 feet, the top of the wheel case being 9 feet above the operating floor.

The wheels are of the Abner Doble Company's design, and are mounted on the overhanging ends of the two-bearing shafts. These shafts are hollow-forged, oil-tempered, 3½ per cent nickel-steel, and measure 10 inches and 7 inches respectively in the bearing journals. The bearings are of the Doble ring-oiling, revolving-shell type, and are provided with water circulation. The wheels are equipped with Ellipsoidal Buckets, and the nozzles are of the Doble Needle Regulating type, arranged for operation by hydraulic governors, or by hand. All parts of the regulating apparatus of the nozzles are above the floor and readily accessible. Balanced relief valves are provided on each wheel as a precaution against excessive pressure in the pressure pipe.

Two 50-horse-power Doble Tangential Water Wheels drive the 30-kilowatt exciters. These wheels are provided with Doble Needle Regulating Nozzles for hand operation, and the housings have plate-glass sides which allow the action of the water upon the buckets, as well as the perfect form of the jet issuing from the needle nozzle, to be observed when the machines are running.

Tests conducted on the Cornell Power Plant gave the following efficiencies for the water wheels:

	¼ load.	½ load.	¾ load.	Full load.	25% overload.
Main Wheels	70.8%	77.5%	79.8%	80.7%	82.1%
Exciter Wheels	77.85%	82.4%	83.6%	84.5%	84.4%

In making these tests the windage and friction of the generators, both on the main units and the exciters, were charged against the water wheels. It must be considered, also, that these wheels operate under a head of 134 feet, which is commonly regarded as a head more suitable for turbines.

NOTE—A complete description of this power plant, together with interesting information relating to Cornell University and its scientific school, Sibley College, will appear in Doble Bulletin No. 10.

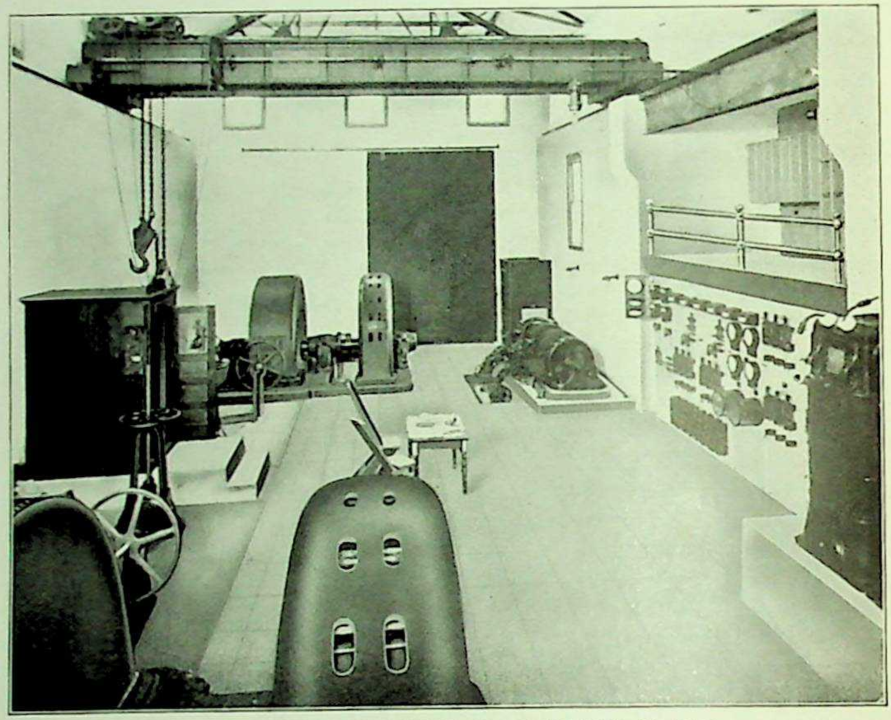

Fig. 50. SANTA ANA RIVER No. 2 POWER PLANT

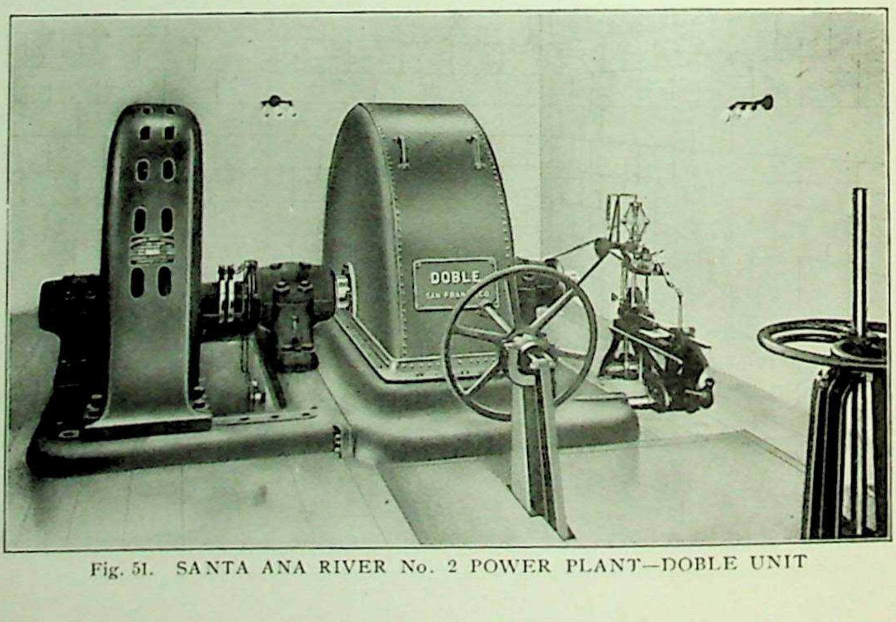

Fig. 51. SANTA ANA RIVER No. 2 POWER PLANT—DOBLE UNIT

SANTA ANA RIVER No. 2 POWER PLANT

The latest power plant of the Edison Electric Company, Los Angeles, Cal., to be placed in operation is that known as Santa Ana River No. 2, situated in Santa Ana Canyon in the vicinity of Redlands. Water for this plant is diverted from the tailrace of Santa Ana Plant No. 1 and is conveyed about two miles down the canyon through a series of 11 concrete-lined tunnels which have a water-carrying cross-section of 4½ feet by 5 feet. From the forebay at the lower end of the last tunnel, the pressure main is carried to the power house, 305 feet below. This pressure pipe consists of 645 feet of 36-inch riveted steel pipe. At the power station it branches by means of a curved "Y" to the two hydro-electric units.

Each unit consists of a 500-kilowatt, three-phase, 50-cycle, 750-volt alternator directly driven by an 800-horse-power Doble Tangential Water Wheel, the speed being 176 revolutions per minute. Water is delivered to each wheel through a Doble Needle Regulating and Deflecting Nozzle. Each unit is regulated by means of a hydraulic governor connected to the deflecting element of the nozzle.

Two 40-horse-power Doble Wheels, provided with deflecting nozzles controlled by governors, are used to drive the exciters.

This power plant transmits current at 33,000 volts, and feeds into the Edison Electric Company's main 86-mile transmission line leading to Los Angeles.

NEW ELECTRA POWER PLANT INSTALLATION

A new installation at the Electra Power Plant of the California Gas and Electric Corporation includes three 8,000-horse-power Doble Tangential Water Wheels, each being of the same general design and capacity as the 8,000-horse-power Doble Wheel installed in 1904 in the de Sabla Plant for the same corporation (described on pages 14 and 53).

One of the large Electra wheels operates under a head of 1,250 feet at 400 revolutions per minute, and drives a 5,000-kilowatt alternator. The other two 8,000-horse-power wheels drive a 5,000-kilowatt generator, forming a double unit for utilizing water from two separate sources under different heads. The design of this unit is an unusual one, inasmuch as each wheel has sufficient capacity to drive the generator at full load.

One of the wheels is driven by a single jet under a head of 1,465 feet, the water being taken directly from the main gravity conduit. The other wheel is driven by a single jet under a head of 1,250 feet, the source of supply being a large reservoir at the end of the main conduit. This arrangement permits the operation of the generator at full load, by running either wheel at its full capacity or by running both wheels under partial loads, according to the conditions of the water supply. These operating conditions are only made possible by the use of Doble Needle Regulating Nozzles which regulate the quantity of water delivered to each wheel. The hydraulic part of this unit is capable of delivering 16,000 horse-power.

The speed of all three Electra wheels is unusually high (400 revolutions per minute), considering the size of the machines, but is permitted by the use of specially designed Doble Bearings, similar to those so successfully introduced in the large de Sabla wheel.

Each of the three Electra wheels is operated from a Doble Needle Regulating and Deflecting Nozzle, the deflecting element in each case being controlled by a suitable hydraulic governor.

A 200-horse-power Doble Wheel operating under a head of 1,465 feet, with a single jet, at 720 revolutions per minute, furnishes power for the exciter.

An interesting feature brought out in the design of the new Electra Power Plant is that in the installation of the two 5,000-kilowatt units but 0.288 square feet of floor space is required per kilowatt. This area includes room for transformers, switches, and other accessories, and is but one-fourth the floor space per kilowatt required for the original Electra Plant, installed five years previous.

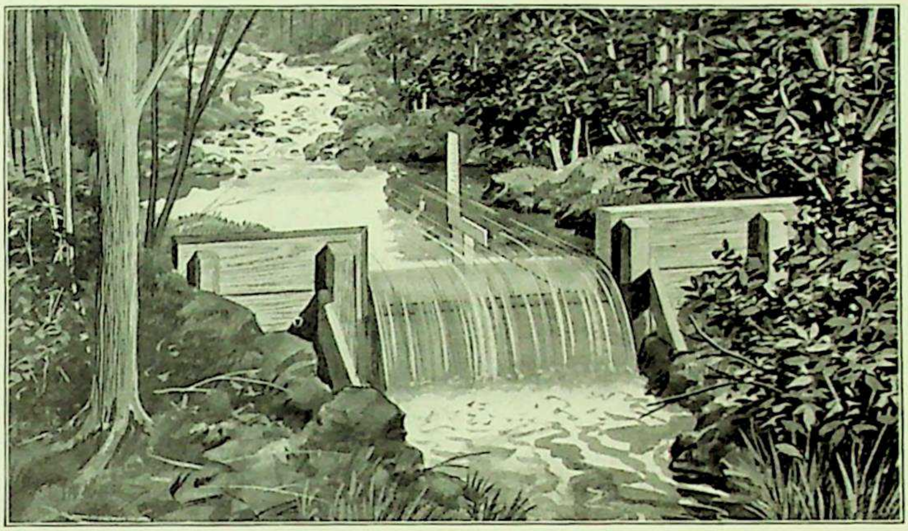

Fig. 52.
SHARP-CRESTED RECTANGULAR WEIR

MEASUREMENT OF WATER

Running water may be conveniently measured, **First,** by means of a weir. This method will give the most accurate results when properly used. **Second,** by estimating the cross-sectional area and the mean velocity of the stream, and multiplying them together.

These two methods are briefly described in what follows:

Weir Measurements.—For estimating the discharge of small streams, a weir may be made by cutting a rectangular notch in a wooden plank (Fig. 52). The length of this notch should be at least three times its depth and about two-thirds the width of the stream. The bottom and sides of the notch must be beveled on the down-stream side, so that the up-stream edges are sharp.

The weir should be set at right angles to the direction of the current, with the sharp edges on the up-stream side, at a point where the water above the weir moves quietly through some small pond. By setting the weir properly, a pond may be created. The bottom of the weir notch, which is the crest of the weir, must be level. The water must discharge freely into the air. For accurate measurements stiff metallic plates with sharp straight edges should be used. Great care is necessary to set the weir so that no water leaks under it or around the ends. The depth of the pond above the weir should be greater than three times the head of water on the crest, and a similar or greater distance should exist between the vertical edges of the weir and the banks of the stream.

The height of the water surface above the crest of the weir should be measured about six feet up stream from the weir plank. At the point selected a stake may be driven, and in it a nail, so that the top of the nail is exactly level with the crest of the weir. The head on the weir is then the distance from

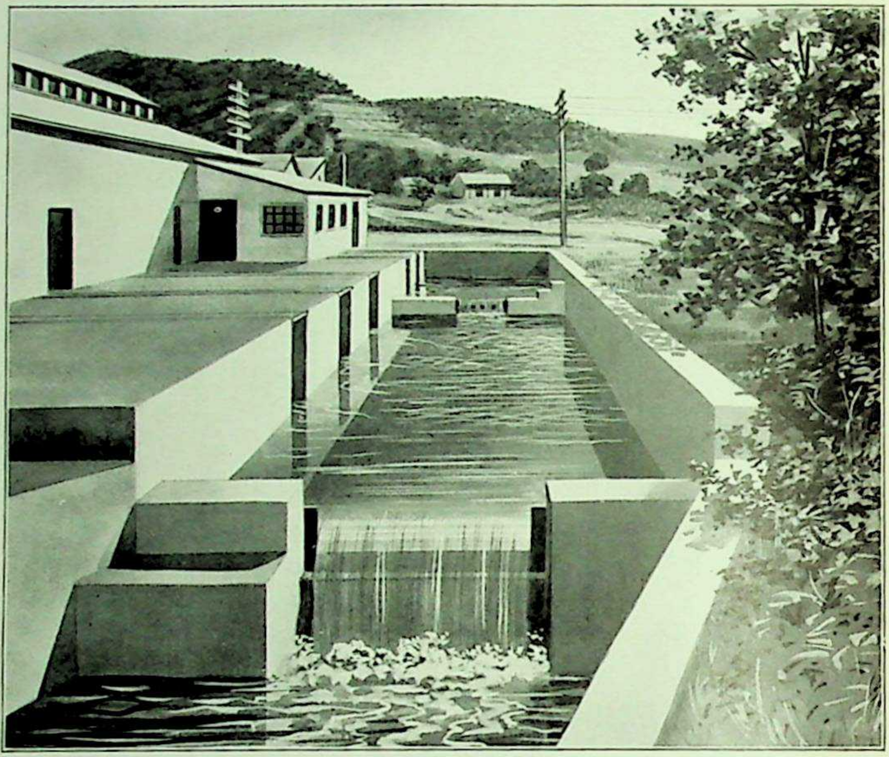

Fig. 53.

WEIR FOR MODERN POWER PLANT

the top of the nail to the surface of the water. This may be measured to thousandths of a foot with a hook gauge. Approximate results can be obtained with a two-foot rule.

The discharge may be calculated by Francis' formula,

(A) $$Q=3.33\,(L-0.2\,H)\,H^{\frac{3}{2}}$$

in which (Q) is the quantity of water discharged in cubic feet per second, (L) the length of the weir in feet, and (H) the head on the crest in feet.

This formula may also be expressed as

(B) $$q=0.4\,(l-0.2\,h)\,h^{\frac{3}{2}}$$

in which (q) is the quantity of water discharged in cubic feet per minute, and (l) and (h) are expressed in inches.

The following table, based on Francis' formula, gives the discharge in cubic feet per minute, per inch length of a sharp-crested rectangular weir, under heads from 1-16 inch to 24 15-16 inches. These values correspond to $3.33\ H^{\frac{3}{2}}$ in formula (A) or $0.4\ h^{\frac{3}{2}}$ in formula (B). Multiplying the value taken from the table by the length of the weir crest in inches less 0.2 times the head in inches, gives the total discharge.

When the velocity of the approaching water is less than ½ foot per second, the result obtained as above is fairly accurate. When the velocity of approach is greater than ½ foot per second, a correction should be applied, for which refinement the reader is referred to the engineering handbooks.

WEIR TABLE

FLOW IN CUBIC FEET PER MINUTE FOR EACH INCH IN WIDTH AND FOR DEPTHS FROM 1/16 TO 24 15/16 INCHES

	0	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16
0	.000	.0063	.018	.032	.05	.07	.092	.116	.141	.169	.198	.228	.26	.293	.327	.363
1	.4	.438	.477	.518	.559	.602	.645	.689	.735	.781	.829	.877	.926	.976	1.027	1.079
2	1.131	1.185	1.239	1.294	1.35	1.407	1.464	1.522	1.581	1.641	1.701	1.762	1.824	1.887	1.95	2.014
3	2.078	2.144	2.21	2.276	2.344	2.412	2.48	2.549	2.619	2.69	2.761	2.832	2.905	2.978	3.051	3.125
4	3.2	3.275	3.351	3.428	3.505	3.582	3.66	3.738	3.818	3.898	3.979	4.06	4.142	4.223	4.305	4.388
5	4.472	4.556	4.641	4.726	4.812	4.898	4.984	5.072	5.16	5.248	5.336	5.426	5.515	5.606	5.696	5.788
6	5.88	5.972	6.064	6.156	6.25	6.344	6.438	6.533	6.628	6.721	6.82	6.918	7.015	7.113	7.21	7.308
7	7.408	7.508	7.608	7.708	7.808	7.91	8.011	8.112	8.216	8.319	8.42	8.525	8.63	8.734	8.84	8.946
8	9.052	9.158	9.264	9.372	9.478	9.586	9.694	9.804	9.913	10.024	10.132	10.242	10.352	10.464	10.576	10.688
9	10.8	10.912	11.026	11.139	11.254	11.367	11.482	11.597	11.712	11.827	11.944	12.062	12.178	12.296	12.413	12.531
10	12.648	12.767	12.887	13.007	13.126	13.248	13.368	13.488	13.61	13.731	13.853	13.976	14.1	14.222	14.344	14.468
11	14.592	14.718	14.844	14.968	15.094	15.219	15.346	15.472	15.6	15.728	15.854	15.982	16.112	16.24	16.368	16.498
12	16.628	16.758	16.888	17.02	17.15	17.281	17.413	17.545	17.677	17.81	17.944	18.076	18.21	18.345	18.48	18.614
13	18.749	18.884	19.02	19.156	19.292	19.429	19.566	19.704	19.841	19.977	20.117	20.256	20.394	20.534	20.673	20.813
14	20.954	21.094	21.234	21.376	21.518	21.659	21.801	21.943	22.086	22.23	22.372	22.516	22.659	22.804	22.948	23.093
15	23.238	23.383	23.529	23.675	23.821	23.968	24.115	24.262	24.409	24.556	24.704	24.853	25.003	25.151	25.301	25.449
16	25.6	25.75	25.901	26.052	26.202	26.354	26.505	26.657	26.809	26.962	27.115	27.268	27.421	27.575	27.728	27.882
17	28.037	28.192	28.347	28.502	28.658	28.814	28.97	29.126	29.283	29.44	29.597	29.755	29.913	30.071	30.229	30.388
18	30.547	30.706	30.866	31.026	31.186	31.346	31.507	31.667	31.829	31.99	32.152	32.314	32.476	32.638	32.801	32.964
19	33.128	33.291	33.455	33.62	33.784	33.948	34.113	34.278	34.444	34.61	34.776	34.942	35.108	35.272	35.442	35.61
20	35.777	35.945	36.114	36.281	36.45	36.619	36.788	36.957	37.127	37.297	37.467	37.638	37.808	37.979	38.15	38.322
21	38.494	38.666	38.838	39.01	39.183	39.356	39.53	39.702	39.876	40.052	40.225	40.399	40.574	40.749	40.924	41.1
22	41.276	41.452	41.628	41.804	41.98	42.16	42.34	42.516	42.691	42.869	43.048	43.226	43.404	43.582	43.76	43.942
23	44.122	44.3	44.48	44.66	44.843	45.024	45.204	45.386	45.568	45.75	45.932	46.114	46.296	46.48	46.664	46.848
24	47.032	47.216	47.4	47.582	47.768	47.952	48.136	48.32	48.508	48.696	48.882	49.068	49.254	49.44	49.628	49.813

Measurement of Cross-Section and Average Velocity.—Select a place where the stream is for some distance (the longer, the better) of fairly uniform cross-section and velocity, and free from counter-currents, eddies, rapids, still water, and other irregularities. Measure off a straight course over which the floats are to pass. From 50 feet for slow streams to 150 feet for rapid streams will answer. Plant two range poles at each end of the course. Prepare a careful cross-section, measuring the depth at a number of points, and the total width, and divide the stream into longitudinal sections by means of poles or buoys.

Observe the number of seconds required for floats to pass over the course in each section of the stream. From this the velocity in feet per second for each section may be estimated.

The area of each separate section of the stream, multiplied by its mean velocity, will give the discharge of that section. The sum of the discharges by sections will give the discharge of the stream.

To obtain even approximately reliable results, the floats must reach nearly to the bottom of the stream, must stand upright, and project as little as possible above the surface of the stream. Tin tubes or wooden rods of adjustable length, weighted at one end, are usually employed. Several observations should be taken for each section, and averaged.

A more accurate method for estimating the velocity of moving water at any point is afforded by the current meter, a delicate instrument extensively used by the United States Geological Survey. For directions on its use consult Water Supply and Irrigation Paper No. 94.

MINER'S INCH

The miner's inch is a measure of water which was first adopted by ditch companies in the State of California, and has been introduced to a limited extent in other Western States. The amount of water represented by a miner's inch is somewhat indefinite, as it varies in almost every locality, because of the different heads above the center of the aperture used by the water companies.

A miner's inch of water, legal measure, in California (see Water Rights, State of California, Civil Code, Section 1415) is that quantity of water which will flow through an opening of one square inch in the bottom or side of a vessel under a pressure of four inches above the opening. Fifty of the above "Miner's Inches" are equivalent to the discharge of one cubic foot of water a second.

The above mentioned act was amended in 1903 so as to read: "Each square inch of the opening represents a miner's inch, and is equal to a flow of 1½ cubic feet of water per minute."

The value of the miner's inch as expressed in the amendment (equivalent to a flow of 1½ cubic feet of water per minute) is now commonly accepted. Forty of these miner's inches are equivalent to the discharge of one cubic foot of water per second. This value is used throughout this Bulletin.

Although the legal value of the miner's inch for the State of California is now stated as equivalent to 1½ cubic feet per minute—forty of these miner's inches being equivalent to one cubic foot per second—the former value, 50 miner's inches equivalent to a cubic foot per second, is still extensively used in Southern California.

INFORMATION REQUIRED FOR MAKING ESTIMATES

As the conditions under which water wheels may be installed are seldom alike, each installation requiring a separate and frequently special construction, we are unable to quote prices in a publication of this nature. We are, however, always pleased to prepare estimates and make quotations for any installation after we have been furnished with complete data covering the proposed use of our machinery.

Many letters of inquiry received by us do not contain all the information necessary to enable us to make a definite reply, or to prepare suitable estimates for the proposed work. Additional correspondence is necessary, consuming time that is valuable to both parties.

Correspondents will therefore please furnish the following data, or as much thereof as may apply to their particular cases:

1. **Head of Water.**—State the full head or vertical distance, in feet, from the surface of headwater or source of supply (ditch, flume, reservoir or forebay) to the floor of the power house, or the point where the wheel is to be located; mention if the head is variable or constant.

If an estimate is required for turbines, state head from the surface of headwater to the surface of tailwater.

2. **Quantity of Water.**—Give the amount of water available, in cubic feet or gallons per minute or in miner's inches. If the quantity of water is variable at different seasons, state the maximum and minimum flow, and also what portion of the maximum flow it is desired to utilize.

3. **Hydraulic Conduit.**—State the character of hydraulic conduit (flume, ditch or pipe) used to carry the water to the top of the pressure pipe; also give, if possible, the size, velocity of flow, or grade of conduit, and its actual carrying capacity.

4. **Condition of Water.**—State whether water is clear, gritty, or muddy.

5. **Tail Water.**—If the quantity of discharge water is to be kept constant by reason of irrigating or other conditions, please mention the fact so that proper arrangements may be made for controlling the load.

6. **Pipe Line.**—State the length along proposed pipe line from source of supply to the wheel. In case the pressure pipe line is already laid, give the diameters and lengths of the different sizes of pipe, if the pipe is of more than one size. A profile of the pipe line is essential, particularly if it is desired that the estimate include the furnishing of the pipe.

7. **Storage Capacity.**—If storage capacity is to be provided at the head of the pipe line, give the dimensions of the reservoir, or state its capacity.

8. Horse-Power Desired.—State the maximum and minimum capacity in horse-power which is desired.

9. Purpose of Water Wheels.—Mention specifically the character and speed of machinery to be driven, and whether it is to be driven by direct, belt, or other connection. If a belt drive is required, give the dimensions and speed of the driven pulley, and its distance from the water-wheel pulley; also state the direction in which the wheel is to run. If the water wheel is to be used for pumping purposes, give the quantity of water to be pumped and the head.

If an estimate is required for turbines, state whether they are to be installed vertically or horizontally, and what their direction of rotation is to be.

10. Hydro-Electric Units.—If the water wheel is to drive an electric generator and the estimate is to include the entire unit, state the type of generator (direct current or alternating current), its kilowatt capacity and voltage, and the speed desired. If an alternating-current generator, give also the frequency and phase. In case the water wheel is to drive a generator already purchased, state of what manufacture, its kilowatt capacity, speed, and the size of shaft. In all cases state whether the current is to be used for power transmission or lighting purposes, or both.

11. Number of Water Wheels.—State the number of water wheels desired, and whether two or more wheels are to be used to drive one unit.

12. Speed of Water Wheels.—State the limits of speed for which the wheel may be built, and what speed is preferred.

13. Regulation Desired.—State the degree of regulation desired and whether any particular make of governor is preferred.

14. Time for Estimates.—Give the date you wish the estimates placed in your hands, or, in case of competitive work, the date the bids will be opened.

15. Address.—Write plainly full address, giving postoffice, county, and state; and, in case of foreign correspondents, the colony, or province, and country.

CANADIAN LICENSEE

All inquiries relating to proposed water wheel installations in the Dominion of Canada should be forwarded direct to the John McDougall Caledonian Iron Works Co., Ltd., of Montreal. The McDougall Company is the sole licensee for the manufacture of the Doble System of Water Wheels in Canada, and is prepared to furnish estimates on Doble Water Wheels in all sizes and for all heads, and to execute the work promptly and with the highest degree of skill.

ABNER DOBLE COMPANY

SAN FRANCISCO, U. S. A.

DATA SHEET FOR ESTIMATES

(For explanation, see page 63)

1. Head of Water

State the full head or vertical distance in feet, from the surface of headwater or source of supply (ditch, flume, reservoir, or forebay) to the floor of the power house, or the point where the wheel is to be located; mention if the head is variable or constant. If an estimate is required for turbines, state head from the surface of headwater to the surface of tailwater.

2. Quantity of Water

Give the amount of water available in cubic feet or gallons per minute or in miner's inches. If the quantity of water is variable at different seasons, state the maximum and minimum flow, and also what portion of the maximum flow it is desired to utilize.

3. Hydraulic Conduit

State the character of hydraulic conduit (flume, ditch, or pipe) used to carry the water to the top of the pressure pipe; also give, if possible, the size, velocity of flow, or grade of conduit, and its actual carrying capacity.

4. Condition of Water

State whether water is clear, gritty, or muddy.

5. Tail Water

If the quantity of discharge water is to be kept constant by reason of irrigating or other conditions, please mention the fact so that proper arrangements may be made for controlling the load.

6. Pipe Line

State the length along proposed pipe line from source of supply to the wheel. In case the pressure pipe line is already laid, give the diameters and lengths of the different sizes of pipe, if the pipe is of more than one size. A profile of the pipe line is essential, particularly if it is desired that the estimate include the furnishing of the pipe.

7. Storage Capacity

If storage capacity is to be provided at the head of the pipe line, give the dimensions of the reservoir, or state its capacity.

8. Horse-power Desired

State the maximum and minimum capacity in horse-power which is desired.

9. *Purpose of Water Wheels*..

....

Mention specifically the character and speed of machinery to be driven, and whether it is to be driven by direct, belt, or other connection. If a belt drive is required, give the dimensions and speed of the driven pulley, and its distance from the water-wheel pulley; also state the direction in which the wheel is to run. If the water wheel is to be used for pumping purposes, give the quantity of water to be pumped and the head.

If an estimate is required for turbines, state whether they are to be installed vertically or horizontally, and what their direction of rotation is to be.

10. *Hydro-Electric Units*..

....

If the water wheel is to drive an electric generator and the estimate is to include the entire unit, state the type of generator (direct-current or alternating-current), its kilowatt capacity and voltage, and the speed desired. If an alternating-current generator, give also the frequency and phase. In case the water wheel is to drive a generator already purchased, state of what manufacture, its kilowatt capacity, speed, and the size of shaft. In all cases state whether the current is to be used for power transmission or lighting purposes, or both.

11. *Number of Water Wheels*..

State the number of water-wheels desired and whether two or more wheels are to be used to drive one unit.

12. *Speed of Water Wheels*..

State the limits of speed for which the wheels may be built and what speed is preferred.

13. *Regulation Desired*..

State the degree of regulation desired and whether any particular make of governor is preferred.

14. *Time for Estimates*..

Give the date you wish the estimates placed in your hands, or, in case of competitive work, the date the bids will be opened.

15. *Name of Firm or Corporation*..

Location of Plant..

General Manager..

Engineer in Charge..

Signature..

Address..

....

Date..

DOBLE WATER WHEEL TABLES

The calculations upon which the Doble Water Wheel Tables are based are made in the foot-pound-minute system. In order to calculate the results with sufficient accuracy for local conditions, it was found necessary to make proper allowances for temperature and latitude. Therefore the computations were based on a temperature of 50° F., taken as the average temperature of California, and a latitude of 38°, the average latitude of California.

The tables have been carried out for different diameters of jets and for effective heads from 10 to 2,550 feet. These computations give effective horse-powers up to 5,000 horse-power for the higher heads. The diameters of wheels have been carried up to 10 feet.

We desire to call special attention to the fact that these tables have been computed to cover average conditions and that they, in no way, express the limits of wheels which we have constructed or are in a position to build. As noted on preceding pages, we have built several water wheels which are operated by single jets of water with diameters up to and over 7 inches. In capacities we have built wheels for the actual development of water power in sizes up to 9,000 horse-power.

For ordinary conditions it may be assumed that, for the maximum allowable speed at which a wheel should operate, the diameter—expressed in feet—of the wheel will be equal to the diameter—expressed in inches—of the jet required for the given horse-power. The result gives the minimum pitch diameter of wheel, the speed of which can be readily obtained from the table. For example, a 1½-inch jet would require a 1½-foot or 18-inch wheel. For a given horse-power, say 60 horse-power, under 360-foot head, the maximum allowable speed would be 891 revolutions per minute. In special cases deviation from this rule may be made.

DOBLE WATER WHEEL TABLES

Effective Head in Ft. Hydrostatic Pressure in Lbs. per Sq. In.	H-P. per Sq. In. of Jet Spouting Velocity	EFFECTIVE HORSE-POWER CUBIC FEET PER MINUTE DIAMETER OF JET ½″	⅝″	¾″	1″	1¼″	1½″	1¾″	2″	2¼″	2½″	3″	3½″	4″	4½″
10 4.33	0.16 1522	0.03 2.07	0.05 3.24	0.07 4.67	0.12 8.30	0.19 12.97	0.28 18.67	0.38 25.41	0.50 33.19	0.63 42.01	0.78 51.87	1.12 74.69	1.53 102	2.00 133	2.53 168
15 6.50	0.29 1863	0.06 2.54	0.09 3.97	0.13 5.72	0.23 10.16	0.36 15.88	0.52 22.87	0.70 31.13	0.92 40.65	1.16 51.45	1.43 63.52	2.06 91.47	2.81 124	3.66 163	4.64 206
20 8.66	0.45 2152	0.09 2.93	0.14 4.58	0.20 6.60	0.44 11.74	0.55 18.34	0.79 26.41	1.08 35.94	1.41 46.94	1.79 59.41	2.21 73.35	3.17 106	4.33 144	5.64 188	7.14 238
25 10.83	0.63 2406	0.12 3.26	0.19 5.13	0.28 7.38	0.49 13.12	0.77 20.50	1.11 29.52	1.51 40.18	1.97 52.48	2.50 66.43	3.08 82.01	4.44 118	6.04 161	7.89 210	9.98 266
30 13.00	0.83 2635	0.16 3.59	0.25 5.61	0.36 8.08	0.65 14.37	1.01 22.46	1.46 32.34	1.99 44.02	2.59 57.49	3.28 72.77	4.05 89.83	5.71 129	7.94 176	10.37 230	13.12 291
35 15.17	1.04 2846	0.20 3.88	0.32 6.06	0.46 8.73	0.82 15.52	1.28 24.26	1.84 34.93	2.50 47.55	3.27 62.10	4.14 78.60	5.11 97.03	7.35 140	10.00 190	13.07 248	16.54 314
40 17.34	1.27 3043	0.25 4.15	0.39 6.48	0.56 9.34	1.00 16.59	1.56 25.93	2.25 37.34	3.05 50.83	3.99 66.39	5.05 81.02	6.25 104	8.98 149	12.25 203	15.97 266	20.21 336
45 19.50	1.52 3228	0.30 4.40	0.47 6.88	0.67 9.90	1.19 17.60	1.86 27.51	2.68 39.61	3.65 54.54	4.76 70.41	6.03 89.12	7.44 110	10.72 158	14.59 216	19.05 282	24.11 356
50 21.67	1.78 3397	0.35 4.64	0.54 7.25	0.78 10.43	1.39 18.56	2.18 28.99	3.14 41.74	4.27 56.83	5.58 73.37	7.06 93.72	8.72 116	12.55 167	17.08 227	22.31 297	28.24 376
60 26.00	2.33 3727	0.46 5.08	0.72 7.94	1.03 11.43	1.83 20.33	2.86 31.75	4.12 45.73	5.61 62.25	7.33 81.31	9.28 103	11.46 127	16.50 183	22.46 249	29.32 325	37.12 412
70 30.34	2.94 4025	0.58 5.49	0.90 8.58	1.30 12.35	2.31 21.95	3.61 34.31	5.20 49.40	7.07 67.24	9.24 87.82	11.69 111	14.44 137	20.79 198	28.30 269	36.96 351	46.78 445
80 34.67	3.59 4303	0.71 5.87	1.10 9.17	1.59 13.20	2.82 23.47	4.41 36.67	6.35 52.81	8.64 71.88	11.28 93.89	14.29 119	17.64 147	25.40 211	34.57 288	45.16 376	57.15 475
90 39.01	4.29 4564	0.84 6.22	1.32 9.72	1.89 14.00	3.37 24.90	5.26 38.90	7.58 56.01	10.31 76.24	13.47 99.58	17.05 126	21.05 156	30.31 224	41.26 305	53.88 398	68.20 504
100 43.34	5.02 4811	0.99 6.56	1.54 10.25	2.22 14.76	3.94 26.24	6.16 41.00	8.87 59.04	12.08 80.37	15.78 105	19.97 133	24.65 164	35.50 236	48.32 321	63.11 420	79.87 531
110 47.67	5.79 5046	1.14 6.88	1.78 10.75	2.56 15.48	4.55 27.52	7.11 43.01	10.24 61.93	13.94 84.29	18.20 110	23.04 139	28.44 172	40.96 248	55.75 337	72.81 440	92.15 557
120 52.01	6.60 5271	1.30 7.18	2.03 11.23	2.92 16.17	5.19 28.75	8.10 44.92	11.67 64.68	15.88 88.04	20.74 115	26.25 146	32.41 180	46.67 259	63.52 352	82.96 460	105 582
130 56.34	7.44 5486	1.46 7.48	2.28 11.68	3.29 16.83	5.85 29.92	9.14 46.75	13.15 67.32	17.91 91.63	23.39 120	29.60 151	36.54 187	52.62 269	71.62 367	93.54 479	118 606
140 60.68	8.32 5693	1.64 7.76	2.56 12.13	3.68 17.46	6.55 31.11	10.23 48.51	14.74 69.86	20.06 95.09	26.20 124	33.16 157	40.93 194	58.94 279	80.23 380	105 497	133 629
150 65.01	9.23 5893	1.81 8.04	2.83 12.55	4.08 18.08	7.25 32.14	11.32 50.22	16.30 72.31	22.19 98.43	28.99 129	36.69 163	45.29 201	65.22 289	88.77 394	116 514	147 651
160 69.34	10.16 6086	2.00 8.30	3.12 12.97	4.49 18.67	7.98 33.19	12.47 51.87	17.96 74.68	24.45 102	31.93 133	40.41 168	49.89 207	71.85 299	97.79 407	128 531	162 672
170 73.68	11.13 6274	2.19 8.55	3.42 13.37	4.92 19.25	8.74 34.21	13.66 53.46	19.67 76.98	26.78 105	34.97 137	44.26 173	54.64 214	78.69 308	107 419	140 547	177 693
180 78.01	12.13 6455	2.38 8.80	3.72 13.75	5.36 19.80	9.53 35.21	14.88 55.01	21.43 79.22	29.17 108	38.10 141	48.22 178	59.53 220	85.73 317	117 431	152 563	193 713
190 82.35	13.15 6632	2.58 9.04	4.04 14.13	5.81 20.35	10.33 36.17	16.14 56.52	23.24 81.39	31.64 111	41.32 145	52.30 183	64.56 226	92.97 326	127 443	165 579	209 732
200 86.68	14.20 6804	2.79 9.28	4.36 14.49	6.28 20.87	11.16 37.11	17.43 57.99	25.10 83.50	34.17 114	44.63 148	56.48 188	69.73 232	100 334	137 455	178 594	226 751
210 91.01	15.28 6972	3.00 9.51	4.69 14.86	6.75 21.39	12.00 38.03	18.76 59.42	27.01 85.56	36.76 116	48.02 152	60.77 193	75.02 238	108 342	147 466	192 608	243 770
220 95.35	16.39 7136	3.22 9.73	5.03 15.20	7.24 21.89	12.87 38.92	20.11 60.82	28.96 87.57	39.42 119	51.48 156	65.16 197	80.44 243	116 350	158 477	206 623	261 788
230 99.68	17.52 7297	3.44 9.95	5.37 15.55	7.74 22.39	13.76 39.80	21.50 62.19	31.03 89.54	42.14 122	55.03 159	69.65 201	85.99 249	124 358	169 488	220 637	279 806
240 104.02	18.67 7454	3.67 10.17	5.73 15.88	8.25 22.87	14.66 40.65	22.92 63.52	33.00 91.47	44.91 124	58.66 163	74.25 206	91.66 254	132 366	180 498	235 650	297 823

NOTE—One cubic foot of water per minute = 0.6666 California miner's inches.
One California miner's inch = 1.5 cubic feet per minute.

DOBLE WATER WHEEL TABLES

Effective Head in Feet	REVOLUTIONS PER MINUTE													
	Diameter of Wheel													
	12″	15″	18″	21″	2′ 0″	2′ 6″	3′ 0″	4′ 0″	5′ 0″	6′ 0″	7′ 0″	8′ 0″	9′ 0″	10′ 0″
10	223	178	148	127	111	89	74	56	45	37	32	28	25	22
15	273	218	182	156	136	109	91	68	55	45	39	34	30	27
20	315	252	210	180	157	126	105	79	63	52	45	39	35	31
25	352	282	235	201	176	141	117	88	70	59	50	44	39	35
30	386	309	257	220	193	154	129	96	77	64	55	48	43	39
35	417	333	278	238	208	167	139	104	83	69	59	52	46	42
40	446	356	297	255	223	178	148	111	89	74	64	56	49	45
45	473	378	315	270	236	189	157	118	95	79	67	59	52	47
50	498	398	332	285	249	199	166	124	100	83	71	62	55	50
60	546	437	364	312	273	218	182	136	109	91	78	68	61	55
70	589	472	393	337	295	236	196	148	118	98	84	74	65	59
80	630	504	420	360	315	252	210	157	126	105	90	79	70	63
90	668	535	445	382	335	267	223	167	134	111	95	83	74	67
100	704	564	470	402	352	282	235	176	141	117	100	88	78	70
110	739	591	493	422	369	296	246	185	148	123	105	92	82	74
120	772	617	515	441	386	309	257	193	154	129	110	96	86	77
130	803	643	535	459	402	321	268	201	161	134	115	100	89	80
140	834	667	556	476	417	333	278	208	167	139	119	104	93	83
150	863	690	575	493	431	345	288	216	173	144	123	108	96	86
160	891	713	594	509	446	356	297	223	178	148	127	111	99	89
170	918	735	612	525	459	367	306	230	184	153	131	115	102	92
180	945	756	630	540	473	378	315	236	189	157	135	118	105	95
190	971	777	647	555	485	388	323	243	194	162	139	121	108	97
200	996	797	665	569	498	398	332	249	199	166	142	124	111	100
210	1021	817	681	583	510	408	340	255	204	170	146	128	113	102
220	1045	836	696	597	522	418	348	261	209	179	149	131	116	104
230	1068	855	712	611	534	427	356	267	214	178	153	134	119	107
240	1091	873	728	624	546	437	364	273	218	182	156	136	121	109

DOBLE WATER WHEEL TABLES

Effective Head in Ft. Hydrostatic Pressure in Lbs. per Sq. In.	H-P. per Sq. In. of Jet Spouting Velocity	EFFECTIVE HORSE-POWER CUBIC FEET PER MINUTE Diameter of Jet ½″	⅝″	¾″	1″	1¼″	1½″	1¾″	2″	2¼″	2½″	3″	3½″	4″	4½″
250 108.35	19.85 7607	3.90 10.37	6.09 16.21	8.77 23.34	15.59 41.49	24.36 64.83	35.08 93.36	47.75 127	62.37 166	78.93 210	97.45 259	140 373	191 508	249 664	316 840
260 112.68	21.05 7758	4.13 10.58	6.46 16.53	9.30 23.80	16.54 42.31	25.84 66.12	37.21 95.20	50.64 130	66.15 169	83.72 214	103 264	149 381	203 518	265 677	335 857
270 117.02	22.28 7906	4.38 10.78	6.84 16.84	9.84 24.25	17.50 43.12	27.34 67.38	39.37 97.02	53.59 132	70.00 172	88.59 218	109 269	157 388	214 528	280 690	354 873
280 121.35	23.53 8051	4.62 10.98	7.22 17.15	10.40 24.70	18.48 43.91	28.88 68.61	41.58 98.80	56.60 134	73.92 176	93.56 222	115 274	166 395	226 538	296 703	374 889
290 125.69	24.80 8194	4.87 11.17	7.61 17.46	10.96 25.14	19.47 44.69	30.44 69.83	43.83 101	59.66 137	77.92 179	98.62 226	122 279	175 402	239 547	312 715	394 905
300 130.02	26.10 8334	5.12 11.36	8.01 17.76	11.53 25.57	20.50 45.45	32.03 71.02	46.11 102	62.77 139	81.98 182	104 230	128 284	184 409	251 557	328 727	415 920
310 134.35	27.41 8471	5.38 11.55	8.41 18.05	12.11 25.99	21.53 46.20	33.64 72.19	48.44 104	65.93 141	86.13 185	109 234	135 289	194 416	264 566	344 739	436 936
320 138.69	28.75 8607	5.64 11.74	8.82 18.34	12.70 26.41	22.58 46.95	35.28 73.35	50.80 106	69.15 144	90.31 188	114 238	141 293	203 422	277 575	361 751	457 951
330 143.02	30.04 8720	5.91 11.92	9.24 18.62	13.30 26.82	23.65 47.67	36.95 74.49	53.20 107	72.42 146	94.58 191	120 241	148 298	213 429	290 581	378 763	479 965
340 147.36	31.49 8872	6.18 12.10	9.66 18.90	13.91 27.22	24.73 48.39	38.64 75.61	55.64 109	75.73 148	98.92 194	125 245	155 302	223 435	303 593	396 774	501 980
350 151.69	32.89 9001	6.46 12.27	10.09 19.18	14.53 27.62	25.83 49.09	40.36 76.71	58.11 110	79.10 150	103 196	131 249	161 307	232 442	316 601	413 785	523 994
360 156.02	34.30 9129	6.74 12.45	10.53 19.45	15.16 28.01	26.94 49.79	42.10 77.80	60.62 112	82.51 152	108 199	136 252	168 311	242 448	330 610	431 797	546 1008
370 160.36	35.74 9255	7.02 12.62	10.97 19.72	15.79 28.39	28.07 50.48	43.86 78.87	63.16 114	85.97 155	112 202	142 256	175 315	253 451	344 618	449 808	568 1022
380 164.69	37.20 9379	7.30 12.79	11.41 19.98	16.44 28.78	29.22 51.15	45.65 79.93	65.74 115	89.48 157	117 205	148 259	183 320	263 460	358 627	467 818	592 1036
390 169.03	38.68 9502	7.60 12.95	11.87 20.24	17.09 29.15	30.38 51.82	47.47 80.98	68.35 117	93.04 159	122 207	154 262	190 324	273 466	372 635	486 829	615 1049
400 173.26	40.18 9623	7.89 13.12	12.33 20.50	17.75 29.52	31.56 52.48	49.31 82.01	71.00 118	96.64 161	126 210	160 266	197 328	284 472	387 643	505 840	639 1063
410 177.69	41.69 9742	8.19 13.28	12.79 20.76	18.42 29.89	32.75 53.14	51.17 83.03	73.68 120	100 163	131 213	166 269	205 332	295 478	403 651	524 850	662 1076
420 182.03	43.23 9860	8.49 13.44	13.26 21.01	19.10 30.25	33.95 53.78	53.05 84.03	76.39 121	104 165	136 215	172 272	212 336	306 484	416 659	543 860	687 1089
430 186.37	44.78 9977	8.79 13.60	13.74 21.26	19.78 30.61	35.17 54.41	54.96 85.03	79.13 122	108 167	141 218	178 275	220 340	317 490	431 667	563 871	712 1102
440 190.70	46.35 10092	9.10 13.76	14.22 21.50	20.48 30.96	36.41 55.05	56.88 86.01	81.91 124	111 169	146 220	184 279	228 344	328 495	446 674	582 881	737 1115
450 195.03	47.94 10207	9.41 13.92	14.71 21.75	21.18 31.31	37.65 55.67	58.83 86.98	84.72 125	115 170	151 223	191 282	235 348	339 501	461 682	602 891	762 1127
460 199.36	49.55 10319	9.73 14.07	15.20 21.99	21.89 31.66	38.92 56.28	60.79 87.94	87.56 127	119 172	156 225	197 285	243 352	350 507	477 689	623 900	788 1140
470 203.70	51.17 10421	10.05 14.22	15.70 22.22	22.61 32.00	40.19 56.89	62.80 88.89	90.43 128	123 174	161 228	203 288	251 356	362 512	492 697	643 910	814 1152
480 208.03	52.81 10540	10.37 14.37	16.21 22.46	23.33 32.34	41.48 57.49	64.81 89.83	93.33 129	127 176	166 230	210 291	259 359	373 517	503 701	664 920	840 1164
490 212.37	54.47 10650	10.70 14.52	16.71 22.69	24.07 32.68	42.78 58.09	66.85 90.77	96.26 131	131 178	171 232	217 294	267 363	385 523	524 712	685 929	866 1176
500 216.70	56.15 10759	11.03 14.67	17.23 22.92	24.81 33.01	44.10 58.68	68.91 91.69	99.22 132	135 180	176 235	223 297	276 367	397 528	540 719	706 939	893 1188
510 221.03	57.84 10866	11.36 14.82	17.75 23.15	25.55 33.33	45.43 59.26	70.98 92.60	102 133	139 181	182 237	230 300	284 370	409 533	557 726	727 948	920 1200
520 225.37	59.55 10972	11.69 14.96	18.27 23.38	26.31 33.66	46.77 59.84	73.08 93.50	105 135	143 183	187 239	237 303	292 374	421 539	573 733	748 957	947 1212

DOBLE WATER WHEEL TABLES

Effective Head in Feet	REVOLUTIONS PER MINUTE													
	Diameter of Wheel													
	12″	15″	18″	21″	2′ 0″	2′ 6″	3′ 0″	4 0″	5′ 0″	6′ 0″	7′ 0″	8′ 0″	9′ 0″	10′ 0″
250	1114	891	743	637	557	445	371	278	223	186	159	139	124	111
260	1136	909	757	649	568	454	379	284	227	189	162	142	126	114
270	1158	926	772	662	579	463	386	289	231	193	165	145	129	116
280	1179	943	786	674	589	472	393	295	236	196	168	147	131	118
290	1200	960	799	686	600	480	400	300	240	200	171	150	133	120
300	1220	976	813	697	610	488	407	305	244	203	174	152	136	122
310	1240	992	827	709	620	496	413	310	248	207	177	155	138	124
320	1260	1008	840	720	630	504	420	315	252	210	180	157	140	126
330	1280	1024	853	731	640	512	427	320	256	213	183	160	142	128
340	1299	1039	866	742	650	520	433	325	260	216	186	162	144	130
350	1318	1054	879	753	659	527	439	329	264	220	188	165	146	132
360	1337	1069	891	764	668	535	446	334	267	223	191	167	149	134
370	1355	1084	903	774	678	543	452	339	271	226	194	169	151	136
380	1373	1099	915	785	687	549	458	343	275	229	196	172	153	137
390	1391	1113	927	795	696	557	464	348	278	232	198	174	155	139
400	1409	1127	939	805	704	564	470	352	282	235	201	176	157	141
410	1426	1141	951	815	713	571	475	357	285	238	204	178	159	143
420	1444	1155	962	825	722	578	481	361	289	241	206	180	160	144
430	1461	1169	974	835	730	584	487	365	292	243	209	183	162	146
440	1478	1182	985	844	739	591	493	369	296	246	211	185	164	148
450	1494	1196	996	854	747	598	498	374	299	249	213	187	166	149
460	1511	1209	1007	863	755	604	504	378	302	252	216	189	168	151
470	1527	1222	1018	873	764	611	509	382	305	255	218	191	170	153
480	1543	1235	1029	882	772	617	514	386	309	257	220	193	171	154
490	1559	1248	1039	891	780	624	520	390	312	260	223	195	173	156
500	1575	1260	1050	900	788	630	525	394	315	263	225	197	175	158
510	1591	1273	1061	909	795	636	530	398	318	265	227	199	177	159
520	1606	1285	1071	918	803	643	536	402	321	268	230	201	179	161

DOBLE WATER WHEEL TABLES

Effective Head in Ft. / Hydrostatic Pressure in Lbs. per Sq. In.	H.-P. per Sq. In. of Jet / Spouting Velocity	EFFECTIVE HORSE-POWER / CUBIC FEET PER MINUTE — DIAMETER OF JET													
		½″	⅝″	¾″	1″	1¼″	1½″	1¾″	2″	2¼″	2½″	3″	3½″	4″	4½″
530	61.28	12.03	18.80	27.07	48.13	75.20	108	147	193	244	301	433	590	770	975
229.70	11077	15.10	23.60	33.98	60.41	94.40	136	185	242	306	378	544	740	967	1223
540	63.02	12.37	19.33	27.84	49.50	77.34	111	152	198	251	309	445	606	792	1002
234.01	11181	15.24	23.82	34.30	60.98	95.28	137	187	244	309	381	549	747	976	1235
550	64.78	12.72	19.87	28.62	50.88	79.50	114	156	204	258	318	458	623	814	1030
238.37	11284	15.39	24.01	34.62	61.54	96.16	138	188	246	312	385	554	754	985	1246
560	66.55	13.07	20.42	29.40	52.27	81.68	118	160	209	265	327	470	640	836	1058
242.70	11386	15.53	24.26	34.93	62.10	97.03	140	190	248	314	388	559	761	994	1257
570	68.34	13.42	20.97	30.19	53.68	83.87	121	164	215	272	335	483	658	859	1087
247.04	11487	15.66	24.47	35.24	62.65	97.90	141	192	251	317	392	564	767	1002	1269
580	70.15	13.77	21.52	30.99	55.10	86.09	124	169	220	279	344	496	675	882	1116
251.37	11587	15.80	24.69	35.55	63.20	98.75	142	194	253	320	395	569	774	1011	1280
590	71.97	14.13	22.08	31.79	56.53	88.32	127	173	226	286	353	509	692	904	1145
255.71	11687	15.93	24.90	35.85	63.74	99.60	143	195	255	323	398	574	781	1020	1291
600	73.81	14.49	22.64	32.61	58.10	90.58	130	178	232	293	362	522	710	927	1174
260.04	11785	16.07	25.11	36.16	64.28	100	145	197	257	325	402	579	787	1028	1302
610	75.66	14.86	23.21	33.43	59.43	92.86	134	182	238	301	371	535	728	951	1203
264.37	11883	16.20	25.32	36.46	64.82	101	146	198	259	328	405	583	794	1037	1312
620	77.53	15.22	23.79	34.25	60.89	95.15	137	186	244	308	381	548	746	974	1233
268.71	11980	16.33	25.52	36.75	65.34	102	147	200	261	331	408	588	800	1045	1323
630	79.42	15.59	24.36	35.08	62.37	97.45	140	191	249	316	390	561	764	998	1263
273.04	12077	16.47	25.73	37.05	65.87	103	148	202	263	333	412	593	807	1054	1334
640	81.31	15.96	24.95	35.92	63.86	99.79	144	196	255	323	399	575	782	1022	1294
277.38	12172	16.60	25.93	37.34	66.39	104	149	203	266	336	415	597	813	1062	1344
650	83.23	16.34	25.53	36.77	65.37	102	147	200	261	331	408	588	801	1046	1324
281.71	11267	16.73	26.14	37.63	66.90	105	151	205	268	339	419	602	820	1070	1355
660	85.16	16.72	26.12	37.62	66.88	104	150	205	268	339	418	602	819	1070	1354
286.04	12361	16.85	26.34	37.92	67.42	105	152	206	270	341	421	607	826	1079	1365
670	87.10	17.10	26.72	38.48	68.41	107	154	209	274	346	428	616	838	1094	1388
290.38	12454	16.98	26.53	38.21	67.93	106	153	208	272	344	425	611	832	1087	1376
680	89.05	17.49	27.32	39.34	69.94	109	157	214	280	354	437	629	857	1119	1416
294.71	12547	17.11	26.73	38.49	68.43	107	154	210	274	346	428	616	838	1095	1386
690	91.03	17.87	27.93	40.21	71.49	112	161	219	286	362	447	643	876	1144	1148
299.05	12639	17.23	26.92	38.77	68.93	108	155	211	276	349	431	620	844	1103	1396
700	93.01	18.26	28.53	41.09	73.05	114	164	224	292	370	457	657	895	1169	1479
303.38	12730	17.35	27.12	39.05	69.43	108	156	213	278	351	434	625	851	1111	1406
710	95.01	18.65	29.15	41.97	74.62	117	168	229	298	378	466	672	914	1194	1511
307.71	12820	17.48	27.32	39.33	69.92	109	157	214	280	354	437	629	857	1119	1416
720	97.03	19.05	29.77	42.86	76.20	119	171	233	305	386	476	686	934	1220	1543
312.05	12910	17.61	27.51	39.61	70.41	110	158	216	282	356	440	634	863	1127	1426
730	99.06	19.45	30.39	43.76	77.80	122	175	238	311	394	486	700	953	1245	1575
316.38	12999	17.73	27.70	39.88	70.90	111	160	217	284	359	443	638	869	1134	1436
740	101.10	19.85	31.02	44.66	79.40	124	179	243	318	402	496	715	973	1270	1608
320.72	13088	17.85	27.89	40.16	71.39	112	161	219	286	361	446	642	874	1142	1445
750	103.15	20.25	31.65	45.57	81.02	127	182	248	324	410	506	729	992	1296	1641
325.05	13177	17.97	28.07	40.42	71.87	112	162	220	287	364	449	647	880	1150	1455
760	105.22	20.66	32.28	46.49	82.64	129	186	253	331	418	517	744	1012	1322	1673
329.38	13264	18.09	28.26	40.69	72.34	113	163	222	289	366	452	652	886	1157	1465
770	107.31	21.07	32.92	47.41	84.28	132	190	258	337	427	527	759	1032	1348	1707
333.72	13351	18.20	28.45	40.96	72.82	114	164	223	291	369	455	656	892	1165	1474
780	109.40	21.48	33.57	48.33	85.93	134	193	263	344	435	537	773	1053	1375	1740
338.05	13438	18.32	28.63	41.23	73.29	115	165	224	293	371	458	660	898	1173	1484
790	111.52	21.89	34.21	49.27	87.58	137	197	268	350	443	547	788	1073	1401	1774
342.39	13523	18.44	28.81	41.49	73.76	115	166	226	295	373	461	664	904	1180	1494
800	113.64	22.31	34.86	50.20	89.25	139	201	273	357	452	558	803	1093	1428	1807
346.72	13609	18.56	29.00	41.75	74.22	116	167	227	297	376	464	668	909	1188	1503

DOBLE WATER WHEEL TABLES

Effective Head in Feet	REVOLUTIONS PER MINUTE													
	DIAMETER OF WHEEL													
	12″	15″	18″	21″	2′ 0″	2′ 6″	3′ 0″	4′ 0″	5′ 0″	6′ 0″	7′ 0″	8′ 0″	9′ 0″	10′ 0″
530	1622	1297	1081	927	811	648	511	405	324	270	232	203	180	162
540	1637	1310	1091	935	818	655	546	409	327	273	234	205	182	164
550	1652	1322	1101	944	826	661	551	413	330	275	236	207	184	165
560	1667	1334	1111	953	834	667	556	417	333	278	238	208	185	167
570	1682	1346	1121	961	841	673	561	420	336	280	240	210	187	168
580	1697	1356	1131	969	848	679	566	424	339	283	242	212	189	170
590	1711	1369	1141	978	856	684	570	428	342	285	244	214	190	171
600	1725	1380	1150	986	863	690	575	431	345	288	246	216	192	173
610	1740	1392	1160	994	870	696	580	435	348	290	249	218	193	174
620	1754	1403	1169	1002	877	702	585	439	351	292	251	219	195	175
630	1768	1415	1179	1010	884	707	589	442	354	295	253	221	197	177
640	1782	1426	1188	1018	891	713	594	446	356	297	255	223	198	178
650	1796	1437	1197	1026	898	718	599	449	359	299	257	225	200	180
660	1810	1448	1207	1035	905	724	603	453	362	302	259	226	201	181
670	1824	1459	1216	1042	912	729	608	456	365	304	261	228	203	182
680	1837	1470	1225	1050	919	735	612	459	367	306	262	230	204	184
690	1851	1480	1234	1057	925	740	617	463	370	308	264	231	206	185
700	1864	1490	1243	1065	932	746	621	466	373	311	266	233	207	186
710	1877	1502	1251	1073	939	751	626	469	375	313	268	235	209	188
720	1890	1512	1260	1080	945	756	630	472	378	315	270	236	210	189
730	......	1523	1269	1088	952	761	634	476	381	317	272	238	211	190
740	......	1533	1278	1095	958	767	639	479	383	319	274	240	213	192
750	......	1543	1286	1102	965	772	643	482	386	322	276	241	214	193
760	......	1554	1295	1109	971	777	647	486	388	324	277	243	216	194
770	......	1564	1303	1117	977	782	652	489	391	326	279	244	217	196
780	......	1574	1312	1124	984	787	656	492	394	328	281	246	218	197
790	......	1584	1320	1131	990	792	660	495	396	330	283	247	220	198
800	......	1594	1328	1139	996	797	664	498	398	332	285	249	221	199

DOBLE WATER WHEEL TABLES

Effective Head in Ft. / Hydrostatic Pressure in Lbs. per Sq. In.	H-P. per Sq. In. of Jet. / Spouting Velocity	EFFECTIVE HORSE-POWER / CUBIC FEET PER MINUTE — Diameter of Jet ½″	⅝″	¾″	1″	1¼″	1½″	1¾″	2″	2¼″	2½″	3″	3½″	4″	4½″
810	**115.78**	**22.73**	**35.52**	**51.15**	**90.93**	**142**	**205**	**278**	**364**	**460**	**568**	**818**	**1114**	**1455**	**1841**
351.05	13693	18.67	29.19	42.01	74.69	117	168	229	299	378	467	672	915	1195	1512
820	**117.93**	**23.15**	**36.18**	**52.10**	**92.62**	**145**	**208**	**284**	**370**	**469**	**579**	**834**	**1135**	**1482**	**1876**
355.39	13778	18.79	29.36	42.27	75.15	117	169	230	301	380	470	676	921	1202	1522
830	**120.09**	**23.58**	**36.84**	**53.05**	**94.32**	**147**	**212**	**289**	**378**	**478**	**589**	**849**	**1155**	**1509**	**1910**
359.72	13861	18.90	29.53	42.53	75.60	118	170	232	302	383	473	680	926	1210	1531
840	**122.27**	**24.01**	**37.51**	**54.02**	**96.03**	**150**	**216**	**294**	**384**	**486**	**600**	**864**	**1176**	**1536**	**1945**
364.06	13945	19.01	29.71	42.78	76.06	119	171	233	304	385	475	685	932	1217	1540
850	**124.46**	**24.44**	**38.18**	**54.98**	**97.75**	**153**	**220**	**299**	**391**	**495**	**611**	**880**	**1197**	**1564**	**1979**
368.39	14028	19.12	29.89	43.04	76.51	120	172	234	306	387	478	689	937	1224	1549
860	**126.66**	**24.87**	**38.86**	**55.96**	**99.48**	**155**	**224**	**305**	**398**	**504**	**622**	**896**	**1219**	**1592**	**2014**
372.72	14110	19.24	30.06	43.29	76.96	120	174	236	308	390	481	693	943	1231	1558
870	**128.88**	**25.30**	**39.54**	**56.93**	**101**	**158**	**228**	**310**	**405**	**512**	**633**	**911**	**1240**	**1619**	**2050**
377.06	14192	19.35	30.24	43.54	77.40	121	174	237	310	392	484	697	948	1238	1567
880	**131.10**	**25.74**	**40.22**	**57.92**	**103**	**161**	**232**	**315**	**412**	**521**	**644**	**927**	**1261**	**1647**	**2085**
381.39	14273	19.46	30.41	43.79	77.85	122	175	238	311	394	487	701	954	1245	1576
890	**133.35**	**26.18**	**40.91**	**58.91**	**105**	**164**	**236**	**321**	**419**	**530**	**655**	**943**	**1283**	**1676**	**2121**
385.73	14354	19.57	30.58	44.04	78.29	122	176	240	313	396	489	705	959	1253	1585
900	**135.60**	**26.62**	**41.60**	**59.91**	**106**	**166**	**240**	**326**	**426**	**539**	**666**	**958**	**1305**	**1704**	**2157**
390.06	14434	19.68	30.75	44.28	78.73	123	177	241	315	399	492	709	964	1260	1594
910	**137.87**	**27.07**	**42.30**	**60.91**	**108**	**169**	**244**	**332**	**433**	**548**	**677**	**975**	**1326**	**1732**	**2193**
394.39	14514	19.79	30.92	44.53	79.16	124	178	242	317	401	495	712	970	1267	1603
920	**140.14**	**27.51**	**43.00**	**61.91**	**110**	**172**	**248**	**337**	**440**	**558**	**688**	**991**	**1348**	**1761**	**2229**
398.73	14594	19.90	31.09	44.77	75.60	124	179	244	318	403	497	716	975	1273	1612
930	**142.34**	**27.97**	**43.70**	**62.93**	**112**	**175**	**252**	**343**	**447**	**566**	**699**	**1007**	**1370**	**1790**	**2265**
403.06	14673	20.01	31.26	45.02	80.03	125	180	245	320	405	500	721	980	1280	1621
940	**144.74**	**28.42**	**44.41**	**63.94**	**114**	**178**	**256**	**348**	**455**	**575**	**710**	**1023**	**1393**	**1819**	**2302**
407.40	14751	20.11	31.43	45.26	80.46	126	181	246	322	407	503	724	986	1287	1630
950	**147.05**	**28.87**	**45.12**	**64.97**	**115**	**180**	**260**	**354**	**462**	**585**	**722**	**1039**	**1415**	**1848**	**2339**
411.73	14829	20.22	31.60	45.50	80.88	126	182	248	324	409	506	728	991	1294	1638
960	**149.38**	**29.33**	**45.83**	**66.00**	**117**	**183**	**264**	**359**	**469**	**594**	**733**	**1056**	**1437**	**1877**	**2376**
416.06	14908	20.33	31.76	45.73	81.31	127	183	249	325	412	508	732	996	1301	1646
970	**151.74**	**29.79**	**46.55**	**67.03**	**119**	**186**	**268**	**365**	**477**	**603**	**745**	**1072**	**1460**	**1907**	**2413**
420.40	14985	20.43	31.93	45.97	81.73	128	184	250	327	414	511	736	1001	1308	1655
980	**154.08**	**30.25**	**47.27**	**68.07**	**121**	**189**	**272**	**371**	**484**	**613**	**756**	**1089**	**1482**	**1936**	**2450**
424.73	15062	20.54	32.09	46.21	82.15	128	185	252	329	416	513	739	1006	1314	1664
990	**156.44**	**30.72**	**48.00**	**69.11**	**123**	**192**	**276**	**376**	**491**	**622**	**768**	**1106**	**1505**	**1966**	**2488**
428.07	15139	20.64	32.26	46.45	82.57	129	186	253	330	418	516	743	1011	1321	1672
1000	**158.82**	**32.18**	**48.73**	**70.16**	**125**	**195**	**281**	**382**	**499**	**631**	**780**	**1123**	**1528**	**1996**	**2564**
433.40	15215	20.75	32.41	46.68	82.98	130	187	254	332	420	519	747	1017	1328	1680
1010	**161.20**	**31.65**	**49.46**	**71.22**	**127**	**198**	**285**	**388**	**506**	**641**	**791**	**1140**	**1551**	**2026**	**2526**
437.73	15291	20.85	32.58	46.91	83.40	130	188	255	331	422	521	751	1022	1334	1689
1020	**163.60**	**32.12**	**50.19**	**72.28**	**128**	**201**	**289**	**394**	**514**	**651**	**803**	**1156**	**1574**	**2056**	**2602**
442.07	15366	20.95	32.74	47.14	83.81	131	189	257	335	424	524	754	1027	1341	1697
1030	**166.01**	**32.60**	**50.94**	**73.34**	**130**	**204**	**293**	**399**	**522**	**660**	**815**	**1174**	**1597**	**2086**	**2640**
446.40	15442	21.05	32.90	47.37	84.22	132	189	258	337	426	526	758	1032	1347	1705
1040	**168.44**	**33.07**	**51.68**	**74.41**	**132**	**207**	**298**	**405**	**529**	**670**	**827**	**1191**	**1621**	**2117**	**2679**
450.74	15516	21.16	33.06	47.60	84.63	132	190	259	339	428	529	762	1037	1354	1714
1050	**171.27**	**33.55**	**52.42**	**75.49**	**134**	**210**	**302**	**411**	**537**	**679**	**839**	**1208**	**1644**	**2147**	**2718**
455.07	15591	21.26	33.22	47.83	85.03	133	191	260	340	430	531	765	1042	1361	1722
1100	**183.22**	**35.98**	**56.21**	**80.95**	**144**	**225**	**324**	**441**	**576**	**729**	**899**	**1295**	**1763**	**2302**	**2914**
476.74	15958	21.76	34.00	48.96	87.04	136	196	267	348	441	544	783	1066	1393	1762
1150	**195.86**	**38.46**	**60.09**	**86.53**	**154**	**240**	**346**	**471**	**615**	**779**	**961**	**1384**	**1884**	**2461**	**3112**
498.41	16316	22.25	34.76	50.06	88.99	139	200	273	356	451	556	801	1090	1424	1802
1200	**208.77**	**40.99**	**64.05**	**92.23**	**164**	**256**	**369**	**502**	**656**	**830**	**1025**	**1476**	**2009**	**2623**	**3320**
520.08	16667	22.73	35.51	51.13	90.91	142	205	278	364	460	568	818	1114	1454	1849

DOBLE WATER WHEEL TABLES

Effective Head in Feet	REVOLUTIONS PER MINUTE												
	DIAMETER OF WHEEL												
	15″	18″	21″	2′ 0″	2′ 6″	3′ 0″	4′ 0″	5′ 0″	6′ 0″	7′ 0″	8′ 0″	9′ 0″	10′ 0″
810	1604	1337	1146	1003	802	668	501	401	334	286	251	223	200
820	1617	1345	1153	1008	807	671	504	403	336	288	252	224	202
830	1624	1353	1160	1015	812	676	507	406	338	290	254	226	203
840	1634	1361	1167	1020	817	681	510	408	340	292	255	227	204
850	1643	1369	1174	1027	822	685	513	411	342	293	257	228	205
860	1653	1377	1180	1033	826	689	516	413	344	295	258	230	207
870	1662	1385	1187	1039	831	693	519	416	346	297	260	231	208
880	1672	1393	1194	1045	836	697	522	418	348	298	261	232	209
890	1681	1401	1201	1051	841	701	525	420	350	300	263	234	210
900	1691	1409	1207	1056	845	704	528	423	352	302	264	235	211
910	1700	1417	1214	1063	850	708	531	425	354	304	266	236	213
920	1709	1425	1221	1068	855	712	534	427	356	305	267	237	214
930	1719	1432	1228	1074	859	716	537	430	358	307	268	239	215
940	1728	1440	1234	1080	864	720	540	432	360	309	270	240	216
950	1737	1447	1241	1086	868	724	542	434	362	310	271	241	217
960	1746	1455	1247	1091	873	728	546	437	364	312	273	242	218
970	1755	1463	1254	1097	878	731	548	439	365	313	274	244	219
980	1764	1470	1260	1102	882	735	551	441	367	315	275	245	220
990	1773	1478	1267	1109	887	739	554	443	369	317	277	246	222
1000	1782	1485	1273	1114	891	743	557	446	371	318	278	248	223
1010	1791	1492	1279	1119	895	746	560	448	373	319	280	249	224
1020	1800	1500	1286	1125	900	750	562	450	375	321	281	250	225
1030	1809	1507	1292	1130	904	753	565	452	376	323	282	251	226
1040	1818	1514	1298	1136	909	757	568	454	378	325	284	252	227
1050	1826	1522	1304	1141	913	761	570	456	380	326	285	253	228
1100	1869	1557	1335	1168	934	778	584	467	389	333	292	259	234
1150	......	1592	1365	1195	955	796	597	478	398	341	298	265	239
1200	......	1627	1395	1220	976	813	610	488	406	348	305	271	244

DOBLE WATER WHEEL TABLES

Effective Head in Ft. Hydrostatic Pressure in Lbs. per Sq. In.	H-P. per Sq. In. of Jet Spouting Velocity	EFFECTIVE HORSE-POWER CUBIC FEET PER MINUTE DIAMETER OF JET ½″	⅝″	¾″	1″	1¼″	1½″	1¾″	2″	2¼″	2½″	3″	3½″	4″	4½″
1250 541.75	221.95 17011	43.58 23.19	68.09 36.24	98.06 52.19	174 92.78	272 145	923 209	534 284	697 371	882 470	1089 580	1569 835	2135 1137	2789 1484	3530 1879
1300 563.42	235.40 17348	46.22 23.65	72.22 36.96	104 53.22	185 94.62	289 148	416 213	566 290	740 378	936 479	1156 591	1664 852	2265 1159	2958 1514	3744 1916
1350 585.09	249.11 17678	48.91 24.10	76.43 37.67	110 54.24	196 96.42	306 151	440 217	599 295	783 386	990 488	1223 603	1761 868	2397 1181	3130 1543	3962 1952
1400 606.76	263.03 18003	51.66 24.55	80.71 38.36	116 55.23	207 98.18	323 153	465 221	633 301	826 393	1046 497	1291 614	1860 884	2531 1203	3306 1571	4184 1988
1450 628.43	277.30 18321	54.45 24.98	85.03 39.03	123 56.21	218 99.93	340 156	490 225	667 306	871 400	1103 506	1361 625	1960 899	2668 1224	3485 1599	4410 2023
1500 650.10	291.76 18634	57.29 25.31	89.51 39.57	129 56.96	229 101	358 158	516 228	702 310	917 405	1160 513	1432 633	2062 911	2807 1240	3666 1620	4640 2050
1550 671.77	306.47 18942	60.18 25.66	94.02 40.10	135 57.74	241 103	376 160	542 231	737 314	963 411	1219 520	1504 642	2166 924	2949 1258	3851 1642	4874 2086
1600 693.44	321.42 19246	63.11 26.07	98.61 40.74	142 58.67	252 104	394 163	568 235	773 319	1010 417	1278 528	1578 652	2272 939	3092 1278	4039 1669	5112 2126
1650 715.11	336.60 19544	66.09 26.48	103 41.37	149 59.58	264 106	413 165	595 238	810 324	1057 424	1338 536	1652 662	2379 953	3238 1297	4280 1695	5353 2159
1700 736.78	352.02 19838	69.12 26.88	108 41.99	156 60.47	276 108	432 168	622 242	847 329	1106 430	1400 544	1728 672	2488 968	3387 1317	4424 1720	5599 2191
1750 758.45	367.66 20128	72.19 27.27	113 42.61	162 61.36	289 108	451 170	650 245	884 334	1155 436	1462 553	1805 682	2599 982	3537 1336	4620 1745	5847 2223
1800 780.12	383.53 20413	75.31 27.66	118 43.21	169 62.23	301 111	471 173	678 249	922 339	1205 442	1525 560	1883 691	2711 996	3690 1355	4820 1773	6100 2255
1850 801.79	399.62 20695	78.47 28.04	123 43.81	177 63.08	314 112	490 175	706 252	961 343	1255 449	1589 568	1962 701	2825 1010	3845 1374	5022 1805	6356 2286
1900 823.46	415.93 20972	81.67 28.41	128 44.40	184 63.93	327 114	511 178	735 256	1000 348	1307 455	1654 576	2042 710	2940 1023	4002 1393	5227 1830	....
1950 845.13	432.45 21247	84.91 28.79	133 44.98	192 64.77	340 115	531 180	764 259	1040 353	1353 461	1720 583	2123 720	3057 1036	4161 1410	5434 1854	....
2000 866.80	449.19 21517	88.20 29.15	138 45.55	198 65.59	353 117	551 182	794 262	1080 357	1411 466	1786 590	2205 729	3175 1019	4322 1428	5645 1878	....
2050 888.47	466.14 21785	91.53 29.51	143 46.11	206 66.41	366 118	572 184	824 266	1121 362	1464 472	1853 598	2288 738	3295 1062	4485 1447	5858 1901	....
2100 910.14	483.30 22049	94.90 29.87	148 46.67	214 67.21	380 119	593 187	854 269	1162 366	1518 478	1922 605	2372 747	3416 1075	4650 1464	6073 1924	....
2150 931.81	500.66 22310	98.31 30.22	154 47.23	221 68.01	393 121	614 189	885 272	1204 370	1573 484	1991 612	2458 756	3539 1088	4817 1481	6292 1947	....
2200 953.48	518.23 22567	102 30.57	159 47.77	229 68.79	407 122	636 191	916 275	1246 375	1628 489	2061 619	2544 764	3663 1101	4986 1498	6512 1969	....
2250 975.15	536.00 22822	105 30.92	164 48.31	237 69.57	421 124	658 193	947 278	1289 379	1684 495	2131 626	2631 773	3789 1113	5157 1515	....	....
2300 996.82	553.96 23075	103 31.26	170 48.85	245 70.34	435 125	680 195	979 281	1332 383	1740 500	2203 633	2719 782	3916 1125	5330 1532	....	....
2350 1018.49	572.12 23324	112 31.60	176 49.37	253 71.10	450 126	702 198	1011 284	1376 387	1797 507	2275 640	2809 790	4044 1138	5504 1598	....	....
2400 1040.16	590.48 23571	116 31.93	181 49.90	261 71.85	464 128	725 200	1043 287	1420 391	1855 511	2348 647	2899 798	4173 1150	5681 1564	....	....
2450 1061.83	609.03 23815	120 32.26	187 50.41	269 72.60	478 129	747 202	1076 290	1465 395	1913 516	2422 653	2990 807	4303 1162	5860 1581	....	....
2500 1083.50	627.77 24057	123 32.59	193 50.93	277 73.33	493 130	770 201	1109 293	1510 399	1972 521	2496 660	3082 815	4437 1173	6040 1597	....	....
2550 1105.17	646.69 24296	127 32.92	198 51.43	286 74.06	503 132	794 206	1143 296	1555 403	2032 527	2571 667	3174 823	4571 1185	6222 1613	....	....

DOBLE WATER WHEEL TABLES

Effective Head in Feet	REVOLUTIONS PER MINUTE											
	DIAMETER OF WHEEL											
	18″	21″	2′0″	2′6″	3′0″	4′0″	5′0″	6′0″	7′0″	8′0″	9′0″	10′0″
1250	1660	1423	1245	996	830	622	498	415	356	311	276	249
1300	1693	1451	1270	1016	846	635	508	423	362	317	282	254
1350	1725	1479	1294	1035	862	647	518	431	369	323	287	259
1400	1757	1506	1318	1054	878	659	527	439	376	330	293	264
1450	1788	1533	1341	1073	894	670	536	447	383	335	298	268
1500	1819	1559	1364	1091	910	682	546	455	390	341	303	273
1550	1849	1585	1387	1109	925	693	555	462	396	347	308	277
1600	1879	1610	1409	1127	939	704	564	470	403	352	313	282
1650	......	1635	1431	1145	954	715	572	477	409	358	318	286
1700	......	1660	1452	1162	968	726	581	484	415	363	323	290
1750	......	1684	1474	1179	982	737	589	491	421	368	327	295
1800	......	1708	1494	1196	996	747	598	498	427	374	332	299
1850	......	1732	1515	1212	1010	758	606	505	433	379	337	303
1900	......	1755	1535	1228	1024	768	614	512	439	384	341	307
1950	......	1778	1555	1244	1037	778	622	518	444	389	346	311
2000	......	1800	1575	1260	1050	788	630	525	450	394	350	315
2050	......	1823	1595	1276	1063	797	638	532	456	399	354	319
2100	......	1845	1614	1291	1076	807	646	538	461	403	359	323
2150	......	1867	1633	1307	1089	817	653	544	467	408	363	327
2200	......	1888	1652	1322	1101	826	661	551	472	413	367	330
2250	......	......	1671	1337	1114	835	668	557	477	118	371	334
2300	.. ...	......	1689	1351	1126	845	676	563	483	422	375	338
2350	......	.....	1708	1366	1138	854	683	569	488	427	379	341
2400	......	......	1726	1380	1150	863	690	575	493	431	383	345
2450	......	......	1743	1395	1162	872	697	581	498	436	387	349
2500	......	......	1761	1409	1174	881	704	587	503	440	391	352
2550	......	......	1779	1423	1186	889	711	593	508	445	395	356

LOSS OF HEAD IN PIPE BY FRICTION

HEAD REQUIRED TO OVERCOME FRICTION IN CLEAN IRON PIPES FOR EACH 100 FEET OF LENGTH, AND DISCHARGE IN CUBIC FEET PER MINUTE

Velocity in Ft. per Sec. ☞	1		2		3		4	
Dia. of Pipe in Inches.	Loss of head in ft.	Dis. in cu. ft. p. min.	Loss of head in ft.	Dis. in cu. ft. p. min.	Loss of head in ft.	Dis. in cu. ft. p. min.	Loss of head in ft.	Dis. in cu. ft. p. min.
1	1.637	0.33	6.548	0.65	14.733	0.98	26.192	1.31
2	0.579	1.32	2.316	2.63	5.209	3.95	9.260	5.27
3	0.315	2.94	1.261	5.89	2.835	8.83	5.041	11.78
4	0.204	5.24	0.818	10.47	1.842	15.71	3.274	20.94
5	0.146	8.18	0.585	16.36	1.318	24.54	2.343	32.72
6	0.111	11.78	0.445	23.56	1.003	35.34	1.782	47.12
7	0.088	16.03	0.353	32.07	0.796	48.10	1.414	64.13
8	0.072	20.94	0.289	41.88	0.651	62.82	1.158	83.76
9	0.061	26.50	0.242	53.01	0.546	79.51	0.970	106.01
10	0.052	32.72	0.205	65.44	0.466	98.16	0.828	130.88
11	0.045	39.59	0.179	79.18	0.404	118.77	0.718	158.36
12	0.039	47.12	0.157	94.23	0.354	141.35	0.630	188.47
13	0.035	55.30	0.140	110.59	0.314	165.89	0.559	221.18
14	0.031	64.13	0.125	128.26	0.281	192.39	0.500	256.53
15	0.028	73.62	0.113	147.23	0.254	220.85	0.451	294.47
16	0.025	83.76	0.102	167.52	0.230	251.28	0.409	335.05
17	0.023	94.56	0.093	189.12	0.210	283.68	0.374	378.24
18	0.021	106.01	0.086	212.02	0.193	318.04	0.343	424.05
19	0.020	118.12	0.079	236.24	0.178	354.36	0.316	472.47
20	0.018	130.88	0.073	261.76	0.165	392.64	0.293	523.52
22	0.016	158.36	0.063	316.72	0.143	475.09	0.254	633.45
24	0.014	188.47	0.056	376.93	0.125	565.40	0.223	753.86
26	0.012	221.19	0.049	442.37	0.111	663.56	0.198	884.74
28	0.011	256.52	0.044	513.04	0.100	769.56	0.177	1026.09
30	0.010	294.48	0.040	588.96	0.090	883.43	0.159	1177.91
32	0.009	335.05	0.036	670.10	0.081	1005.15	0.144	1340.20
34	0.008	378.24	0.033	756.48	0.074	1134.72	0.132	1512.96
36	0.007	424.06	0.030	848.11	0.068	1272.17	0.121	1696.23
38	0.007	472.47	0.028	944.93	0.063	1417.40	0.112	1889.86
40	0.006	523.50	0.026	1047.00	0.058	1570.50	0.104	2094.00
42	0.006	577.16	0.024	1154.32	0.054	1731.47	0.096	2308.63
48	0.005	753.88	0.019	1507.76	0.044	2261.64	0.079	3015.52
54	0.004	954.10	0.017	1908.19	0.037	2862.29	0.066	3816.39
60	0.003	1177.89	0.014	2355.79	0.032	3533.68	0.056	4711.58

Velocity in Ft. per Sec. ☞	5		6		7		8	
1	40.925	1.64	58.932	1.96	80.213	2.29	104.768	2.62
2	14.469	6.58	20.836	7.90	28.359	9.22	37.041	10.53
3	7.876	14.72	11.342	17.67	15.437	20.61	20.163	23.56
4	5.116	26.18	7.367	31.41	10.027	36.65	13.096	41.88
5	3.660	40.90	5.271	49.08	7.174	57.26	9.371	65.44
6	2.784	58.89	4.010	70.67	5.458	82.45	7.129	94.23
7	2.210	80.16	3.182	96.20	4.331	112.23	5.657	128.26
8	1.809	104.70	2.605	125.64	3.545	146.58	4.630	167.52
9	1.516	132.51	2.183	159.02	2.971	185.52	3.880	212.02
10	1.294	163.60	1.864	196.32	2.537	229.04	3.313	261.76
11	1.122	197.95	1.615	237.54	2.198	277.13	2.869	316.73
12	0.985	235.59	1.418	282.70	1.930	329.82	2.520	376.94
13	0.873	276.48	1.257	331.77	1.711	387.07	2.235	442.36
14	0.781	320.66	1.125	384.79	1.531	448.92	2.000	513.05
15	0.705	368.09	1.015	441.70	1.381	515.32	1.804	588.94
16	0.640	418.81	0.921	502.57	1.253	586.33	1.637	670.09
17	0.584	472.80	0.841	567.36	1.144	661.92	1.494	756.48
18	0.536	530.06	0.772	636.07	1.050	742.09	1.372	848.10
19	0.494	590.59	0.712	708.71	0.969	826.83	1.265	944.95
20	0.458	654.40	0.659	785.27	0.897	916.15	1.171	1047.03
22	0.397	791.81	0.571	950.17	0.777	1108.53	1.015	1266.90
24	0.348	942.33	0.501	1130.79	0.682	1319.26	0.891	1507.72
26	0.309	1105.93	0.445	1327.11	0.605	1548.30	0.790	1769.48
28	0.276	1282.61	0.398	1539.13	0.541	1795.65	0.707	2052.17
30	0.249	1472.39	0.359	1766.87	0.488	2061.34	0.637	2355.82
32	0.226	1675.25	0.325	2010.30	0.443	2345.35	0.579	2680.40
34	0.207	1891.20	0.297	2269.44	0.405	2647.68	0.529	3025.92
36	0.190	2120.29	0.273	2544.34	0.371	2968.40	0.485	3392.46
38	0.175	2362.33	0.252	2834.80	0.343	3307.26	0.447	3779.73
40	0.162	2617.50	0.233	3141.00	0.317	3664.50	0.414	4188.00
42	0.150	2885.79	0.216	3462.95	0.294	4040.10	0.385	4617.26
48	0.123	3769.40	0.177	4523.28	0.241	5277.16	0.315	6031.03
54	0.103	4770.49	0.149	5724.58	0.202	6678.68	0.264	7632.78
60	0.088	5889.47	0.127	7067.37	0.172	8245.26	0.225	9423.16

LOSS OF HEAD IN PIPE BY FRICTION

HEAD REQUIRED TO OVERCOME FRICTION IN CLEAN IRON PIPES FOR EACH 100 FEET OF LENGTH, AND DISCHARGE IN CUBIC FEET PER MINUTE

Velocity in Ft. per Sec. ☞	9		10		11		12	
Dia. of Pipe in Inches.	Loss of head in ft.	Dis. in cu. ft. p. min.	Loss of head in ft.	Dis. in cu. ft. p. min.	Loss of head in ft.	Dis. in cu. ft. p. min.	Loss of head in ft.	Dis. in cu. ft. p. min.
1	132.597	2.95	163.700	3.27	198.077	3.60	235.728	3.93
2	46.880	11.85	57.877	13.17	70.031	14.48	83.343	15.80
3	25.519	26.50	31.504	29.45	38.120	32.39	45.366	35.34
4	16.575	47.12	20.462	52.35	24.760	57.59	29.466	62.82
5	11.860	73.62	14.642	81.80	17.717	89.98	21.084	98.16
6	9.022	106.01	11.138	117.79	13.477	129.57	16.039	141.35
7	7.159	144.30	8.839	160.33	10.695	176.36	12.728	192.39
8	5.860	188.46	7.234	209.40	8.754	230.34	10.418	251.28
9	4.911	238.53	6.063	265.03	7.336	291.53	8.731	318.03
10	4.194	294.48	5.177	327.20	6.264	359.92	7.455	392.64
11	3.635	356.32	4.487	395.91	5.429	435.50	6.461	475.09
12	3.190	424.06	3.938	471.17	4.765	518.29	5.671	565.41
13	2.829	497.66	3.492	552.95	4.225	608.25	5.028	663.54
14	2.531	577.18	3.125	641.31	3.781	705.45	4.500	769.58
15	2.283	662.56	2.819	736.17	3.411	809.79	4.059	883.41
16	2.072	753.85	2.558	837.62	3.095	921.38	3.684	1005.14
17	1.891	851.04	2.335	945.60	2.825	1040.16	3.362	1134.72
18	1.736	954.11	2.143	1060.12	2.594	1166.13	3.087	1272.15
19	1.602	1063.07	1.977	1181.19	2.392	1299.30	2.847	1417.42
20	1.482	1177.91	1.830	1308.79	2.214	1439.67	2.635	1570.55
22	1.285	1425.26	1.586	1583.62	1.919	1741.98	2.284	1900.35
24	1.128	1696.19	1.392	1884.66	1.684	2073.12	2.004	2261.59
26	1.000	1990.67	1.235	2211.85	1.494	2433.04	1.778	2654.22
28	0.895	2308.69	1.105	2565.21	1.337	2821.74	1.591	3078.26
30	0.807	2650.30	0.996	2944.78	1.205	3239.26	1.434	3533.73
32	0.732	3015.45	0.904	3350.50	1.094	3685.56	1.302	4020.61
34	0.669	3404.15	0.826	3782.39	0.999	4160.63	1.189	4538.87
36	0.614	3816.51	0.758	4240.57	0.917	4664.63	1.092	5088.69
38	0.566	4252.19	0.699	4724.66	0.846	5197.13	1.007	5669.59
40	0.524	4711.50	0.647	5235.00	0.783	5758.49	0.932	6281.99
42	0.487	5194.42	0.601	5771.58	0.727	6348.73	0.865	6925.89
48	0.399	6784.91	0.492	7538.79	0.595	8292.67	0.708	9046.55
54	0.335	8586.88	0.413	9540.97	0.500	10495.07	0.595	11449.17
60	0.285	10601.05	0.352	11778.95	0.426	12956.84	0.507	14134.74

Velocity in Ft. per Sec. ☞	13		14		15		16	
1	276.653	4.25	320.852	4.58	368.325	4.91	419.072	5.24
2	97.812	17.12	113.439	18.44	130.223	19.75	148.165	21.07
3	53.242	38.28	61.749	41.23	70.885	44.17	80.651	47.12
4	34.582	68.06	40.107	73.30	46.041	78.53	52.384	83.76
5	24.745	106.34	28.698	114.52	32.944	122.70	37.483	130.88
6	18.824	153.13	21.812	164.90	25.061	176.68	28.514	188.46
7	14.938	208.43	17.324	224.46	19.888	240.49	22.628	256.52
8	12.227	272.23	14.181	293.17	16.279	314.11	18.521	335.05
9	10.246	344.54	11.883	371.04	13.642	397.54	15.521	424.04
10	8.749	425.36	10.147	458.08	11.648	490.80	13.253	523.52
11	7.580	514.68	8.794	554.27	10.096	593.86	11.486	633.45
12	6.655	612.53	7.718	659.64	8.861	706.76	10.081	753.88
13	5.901	718.84	6.844	774.13	7.857	829.43	8.940	884.72
14	5.281	833.71	6.125	897.81	7.031	961.97	8.000	1026.10
15	4.764	957.02	5.525	1030.64	6.343	1104.26	7.217	1177.88
16	4.323	1088.90	5.014	1172.66	5.756	1256.42	6.548	1340.19
17	3.946	1229.28	4.577	1323.84	5.254	1418.40	5.978	1512.96
18	3.622	1378.16	4.201	1484.17	4.822	1590.18	5.486	1696.20
19	3.341	1535.54	3.875	1653.66	4.448	1771.78	5.061	1889.90
20	3.093	1701.43	3.587	1832.31	4.118	1933.19	4.685	2094.06
22	2.680	2058.71	3.109	2217.07	3.569	2375.43	4.060	2533.79
24	2.352	2450.05	2.728	2638.52	3.132	2826.98	3.564	3015.45
26	2.087	2875.41	2.421	3096.60	2.779	3317.78	3.162	3538.97
28	1.867	3334.78	2.166	3591.30	2.486	3847.82	2.829	4104.34
30	1.683	3828.21	1.952	4122.69	2.241	4417.17	2.550	4711.64
32	1.528	4355.66	1.772	4690.71	2.034	5025.76	2.314	5360.81
34	1.396	4917.11	1.619	5295.35	1.859	5673.59	2.115	6051.83
36	1.281	5512.74	1.486	5936.80	1.706	6360.86	1.940	6784.91
38	1.181	6142.06	1.370	6614.52	1.573	7086.99	1.789	7559.46
40	1.093	6805.49	1.268	7328.99	1.456	7852.49	1.656	8375.99
42	1.016	7503.05	1.178	8080.21	1.352	8657.36	1.539	9234.52
48	0.831	9800.43	0.964	10554.31	1.107	11308.19	1.260	12062.07
54	0.698	12403.26	0.809	13357.36	0.929	14311.46	1.057	15265.56
60	0.595	15312.63	0.690	16490.53	0.792	17668.42	0.901	18846.32

LOSS OF HEAD IN PIPE BY FRICTION

HEAD REQUIRED TO OVERCOME FRICTION IN CLEAN IRON PIPES FOR EACH 100 FEET OF LENGTH, AND DISCHARGE IN CUBIC FEET PER MINUTE

Velocity in Ft. per Sec. ☞	17		18		19		20	
Dia. of Pipe in Inches.	Loss of head in ft.	Dis. in cu. ft. p. min.	Loss of head in ft.	Dis. in cu. ft. p. min.	Loss of head in ft.	Dis. in cu. ft. p. min.	Loss of head in ft.	Dis. in cu. ft. p. min.
1	473.093	5.56	530.388	5.89	590.957	6.22	654.800	6.54
2	167.265	22.39	187.521	23.70	208.936	25.02	231.508	26.34
3	91.048	50.06	102.074	53.01	113.731	55.95	126.018	58.90
4	59.137	89.00	66.298	94.23	73.870	99.47	81.850	101.70
5	42.315	139.06	47.439	147.24	52.857	155.42	58.567	163.60
6	32.189	200.24	36.088	212.02	40.209	223.80	44.553	235.58
7	25.545	272.56	27.638	288.59	31.909	304.62	35.356	320.66
8	20.909	355.99	23.441	376.93	26.118	397.87	28.910	418.81
9	17.522	450.55	19.644	477.05	21.887	503.55	24.252	530.06
10	14.962	556.23	16.773	588.95	18.689	621.67	20.708	654.39
11	12.967	673.04	14.538	712.63	16.195	752.22	17.918	791.81
12	11.381	801.00	12.759	848.11	14.216	895.23	15.752	942.35
13	10.092	940.02	11.314	995.32	12.606	1050.61	13.968	1105.91
14	9.031	1090.23	10.125	1154.37	11.281	1218.50	12.500	1282.63
15	8.147	1251.49	9.134	1325.11	10.177	1398.73	11.276	1472.35
16	7.393	1423.95	8.288	1507.71	9.234	1591.47	10.232	1675.23
17	6.748	1607.52	7.565	1702.08	8.429	1796.64	9.340	1891.20
18	6.193	1802.21	6.946	1908.22	7.739	2014.23	8.572	2120.24
19	5.714	2008.02	6.405	2126.13	7.137	2244.25	7.908	2362.37
20	5.289	2224.94	5.929	2355.82	6.606	2486.70	7.320	2617.58
22	4.584	2692.16	5.138	2850.52	5.725	3008.88	6.344	3167.24
24	4.023	3203.92	4.510	3392.38	5.025	3580.85	5.568	3769.31
26	3.570	3760.15	4.001	3981.34	4.458	4202.52	4.910	4423.71
28	3.193	4360.86	3.580	4617.39	3.989	4873.91	4.420	5130.43
30	2.878	5006.12	3.227	5300.60	3.596	5595.08	3.984	5889.56
32	2.613	5695.86	2.929	6030.91	3.263	6365.96	3.616	6701.01
34	2.387	6430.07	2.676	6808.31	2.982	7186.55	3.304	7564.79
36	2.191	7208.97	2.456	7633.03	2.736	8057.08	3.032	8481.14
38	2.020	8031.92	2.265	8501.39	2.523	8976.85	2.796	9449.32
40	1.870	8899.49	2.096	9422.99	2.336	9946.49	2.588	10469.99
42	1.737	9811.68	1.947	10388.84	2.170	10965.99	2.401	11543.15
48	1.422	12815.95	1.594	13569.83	1.776	14323.71	1.968	15077.59
54	1.194	16219.65	1.338	17173.75	1.491	18127.85	1.652	19081.95
60	1.017	20024.21	1.140	21202.11	1.271	22380.00	1.408	23557.90

Velocity in Ft. per Sec. ☞	21		22		23		24	
1	721.917	6.87	792.308	7.20	865.973	7.53	942.912	7.85
2	255.237	27.65	280.125	28.97	306.169	30.29	333.372	31.60
3	138.934	61.84	152.481	64.79	166.658	67.73	181.465	70.68
4	90.240	109.94	99.038	115.17	108.247	120.40	117.864	125.64
5	64.570	171.78	70.866	179.96	77.445	188.14	84.337	196.32
6	49.120	247.36	53.910	259.14	58.922	270.91	64.157	282.69
7	38.980	336.69	42.781	352.72	46.758	368.75	50.913	384.79
8	31.906	439.75	35.017	460.69	38.273	481.63	41.674	502.57
9	26.738	556.56	29.345	583.06	32.073	609.56	34.923	636.07
10	22.831	687.11	25.057	719.83	27.386	752.55	29.819	785.27
11	19.788	831.40	21.717	871.00	23.736	910.59	25.845	950.18
12	17.367	989.47	19.060	1036.58	20.832	1083.70	22.683	1130.82
13	15.400	1161.20	16.901	1216.50	18.473	1271.80	20.114	1327.09
14	13.781	1346.76	15.125	1410.89	16.531	1475.02	18.000	1539.15
15	12.432	1545.96	13.644	1619.58	14.913	1693.20	16.237	1766.82
16	11.281	1759.00	12.381	1842.76	13.532	1926.52	14.734	2010.28
17	10.297	1985.76	11.301	2080.32	12.352	2174.88	13.460	2269.44
18	9.451	2226.26	10.372	2332.27	11.336	2438.28	12.344	2544.29
19	8.708	2480.49	9.569	2598.61	10.458	2716.73	11.388	2834.85
20	8.070	2748.46	8.857	2879.34	9.681	3010.22	10.541	3141.10
22	6.994	3325.60	7.676	3483.97	8.390	3642.33	9.135	3800.69
24	6.139	3957.78	6.737	4146.24	7.364	4334.71	8.018	4523.17
26	5.446	4644.89	5.977	4866.08	6.533	5087.26	7.114	5308.45
28	4.873	5386.95	5.348	5643.47	5.845	5899.99	6.365	6156.51
30	4.392	6184.03	4.821	6478.51	5.269	6773.00	5.737	7067.67
32	3.987	7036.06	4.375	7371.11	4.782	7706.16	5.207	8041.21
34	3.643	7943.03	3.998	8321.27	4.370	8699.51	4.758	9077.75
36	3.343	8905.20	3.669	9329.26	4.010	9753.31	4.366	10177.37
38	3.083	9921.79	3.383	10394.25	3.698	10866.72	4.026	11339.18
40	2.853	10993.49	3.131	11516.99	3.423	12040.49	3.727	12563.99
42	2.650	12120.31	2.909	12697.47	3.179	13274.62	3.462	13851.78
48	2.170	15831.47	2.381	16585.34	2.603	17339.22	2.834	18093.10
54	1.821	20036.04	1.999	20990.14	2.185	21944.24	2.379	22898.34
60	1.552	24735.79	1.704	25913.69	1.862	27091.58	2.028	28269.48

LOSS OF HEAD IN PIPE BY FRICTION

EXAMPLES ILLUSTRATING THE USE OF THE TABLES ON PAGES 76, 77 AND 78.

EXAMPLE: Having a head of 1,000 feet and 3,000 feet of pipe, carrying 750 cubic feet of water per minute, to find the size of pipe and loss of head, allowing a velocity of 8 feet per second. In the right-hand column under 8-foot velocity, find 756.48 cubic feet (the nearest to 750). Opposite will be found 17-inch pipe, the size required. The loss of head is 1.494 for each 100 feet of pipe or 30 × 1.494 = 44.82 for the total length. The effective head, therefore, is 750 - 44.82 = 705 18 feet.

EXAMPLE: With a head of 500 feet and 1250 feet of pipe carrying 1200 cubic feet of water per minute, to find the size of pipe, allowing 5 per cent loss of head due to friction. For each 100 feet of pipe the loss would be 5 per cent of 500 or 25 feet ÷ 12.50 = 2 feet loss. In the columns find the figures corresponding nearest to 2 feet loss of head and a discharge of 1200 cubic feet. These are found to be 1.977 feet loss for 1181.19 cubic feet, and call for a 19-inch pipe and a velocity of 10 feet per second.

EXAMPLE: Having a head of 700 feet and 2200 feet of 20-inch pipe, carrying 1832 cubic feet per minute, to find effective head and velocity. In the right-hand column opposite 20-inch pipe, find 1832. Opposite this will be found the loss of head in feet for this amount of water for 100 feet of pipe, which is 3.587. Multiply this by the number of hundred feet of pipe, which is 22, which gives 79.9 feet, the loss of head. Therefore the effective head is 700 - 79.9 = 620.1 feet. The velocity is denoted at the top of the column and is 14 feet per second.

LOSS OF HEAD IN CIRCULAR BENDS

HEAD REQUIRED TO OVERCOME RESISTANCE IN CIRCULAR BENDS OF 90°, EXCLUSIVE OF FRICTION.

For a bend of less than 90°, divide the resistance given in this table by 90 and multiply by the number of degrees of bend.

Velocity in Feet per Second	RATIO OF $\frac{\text{RADIUS OF BEND AT CENTER OF PIPE}}{\text{DIAMETER OF PIPE}}$								
	1	1.25	1.5	1.75	2	2.5	3	3.5	4
	LOSS OF HEAD IN FEET								
1	0.001	0.003	0.003	0.002	0.002	0.002	0.002	0.002	0.002
2	0.018	0.013	0.010	0.009	0.009	0.008	0.008	0.008	0.008
3	0.011	0.029	0.021	0.021	0.020	0.019	0.019	0.018	0.018
4	0.073	0.051	0.042	0.038	0.036	0.034	0.033	0.033	0.033
5	0.114	0.080	0.066	0.050	0.056	0.053	0.052	0.052	0.051
6	0.164	0.115	0.095	0.086	0.081	0.077	0.075	0.074	0.074
7	0.224	0.156	0.130	0.117	0.111	0.105	0.102	0.101	0.101
8	0.292	0.204	0.169	0.153	0.144	0.137	0.134	0.132	0.131
9	0.370	0.259	0.214	0.194	0.183	0.173	0.169	0.167	0.166
10	0.456	0.319	0.265	0.239	0.226	0.214	0.209	0.206	0.205
11	0.552	0.386	0.320	0.289	0.273	0.258	0.253	0.250	0.218
12	0.657	0.460	0.381	0.344	0.325	0.308	0.301	0.297	0.296
13	0.771	0.540	0.447	0.401	0.381	0.361	0.353	0.349	0.347
14	0.895	0.626	0.519	0.469	0.442	0.419	0.409	0.405	0.402
15	1.027	0.719	0.596	0.538	0.508	0.481	0.470	0.465	0.462
16	1.169	0.818	0.678	0.612	0.578	0.547	0.535	0.529	0.526
17	1.319	0.923	0.765	0.691	0.652	0.617	0.603	0.597	0.593
18	1.480	1.035	0.858	0.775	0.731	0.692	0.677	0.670	0.665
19	1.648	1.153	0.956	0.863	0.815	0.771	0.754	0.746	0.741
20	1.826	1.278	1.059	0.957	0.903	0.855	0.835	0.826	0.821
21	2.013	1.408	1.167	1.055	0.995	0.942	0.921	0.911	0.905
22	2.209	1.546	1.281	1.157	1.093	1.034	1.011	1.000	0.994
23	2.415	1.690	1.400	1.265	1.194	1.130	1.105	1.093	1.086
24	2.629	1.840	1.525	1.377	1.300	1.231	1.203	1.190	1.183
25	2.853	1.996	1.651	1.495	1.411	1.335	1.305	1.291	1.284

RIVETED HYDRAULIC PIPE

Made of sheet steel plates, ultimate tensile strength 55,000 lbs. per square inch, double-riveted longitudinal joints and single-riveted circular joints. Strength of longitudinal joints, 70%. Strain by safe pressure, ¼ of ultimate strength.

Internal Diam.	Thickness of Plate		Safe Head	Safe Pressure	Weight per lin. ft.
Ins.	U.S. St'd. G'ge	Ins.	Ft.	lbs Sq. In.	lbs
3	18	.050	740	320	2.2
4	18	.050	555	240	2.8
4	16	.062	693	300	3.7
4	14	.078	866	375	4.4
5	18	.050	444	192	3.5
5	16	.062	555	240	4.4
5	14	.078	693	300	5.5
6	18	.050	370	160	4.1
6	16	.062	462	200	5.2
6	14	.078	578	250	6.4
6	12	.109	808	350	8.8
7	18	.050	317	137	4.7
7	16	.062	396	171	5.9
7	14	.078	495	214	7.3
7	12	.109	693	300	10.0
8	18	.050	277	120	5.3
8	16	.062	346	150	6.7
8	14	.078	433	187	8.2
8	12	.109	606	263	11.5

Internal Diam.	Thickness of Plate		Safe Head	Safe Pressure	Weight per lin. ft.
Ins.	U.S. St'd. G'ge	Ins.	Ft.	lbs Sq. In.	lbs
8	10	.140	777	337	14.5
9	16	.062	308	133	7.5
9	14	.078	385	167	9.2
9	12	.109	539	233	12.6
9	10	.140	693	300	16.4
10	16	.062	277	120	8.3
10	14	.078	346	150	10.2
10	12	.109	485	210	14.2
10	10	.140	623	270	18.0
10	8	.171	761	330	21.5
10	3/16	.187	832	361	23.5
11	16	.062	252	109	9.0
11	14	.078	314	136	11.0
11	12	.109	439	190	15.2
11	10	.140	565	245	19.3
11	8	.171	693	300	23.5
11	3/16	.187	757	328	25.5
12	16	.062	231	100	9.9
12	14	.078	289	125	12.2

Internal Diam.	Thickness of Plate		Safe Head	Safe Pressure	Weight per lin. ft.
Ins.	U.S. St'd. G'ge	Ins.	Ft.	lbs Sq. In.	lbs
12	12	.109	401	175	16.7
12	10	.140	519	225	21.0
12	8	.171	635	275	25.6
12	3/16	.187	693	300	27.7
13	16	.062	213	92	10.7
13	14	.078	266	115	13.1
13	12	.109	372	161	17.8
13	10	.140	478	207	22.5
13	8	.171	587	254	27.5
13	3/16	.187	639	277	29.8
14	16	.062	198	86	11.4
14	14	.078	218	107	14.0
14	12	.109	346	150	19.2
14	10	.140	445	193	24.2
14	8	.171	543	235	29.5
14	3/16	.187	594	257	31.9
14	1/4	.250	792	343	42.7
15	16	.062	185	80	12.0
15	14	.078	231	100	14.0

RIVETED HYDRAULIC PIPE—*Continued.*

Internal Diam.	Thickness of Plate		Safe Head	Safe Pressure	Weight per lin. ft.
Ins.	U.S. St'd G'ge	Ins.	Ft.	lbs Sq. In.	lbs
15	12	.109	323	140	20.3
15	10	.140	415	180	25.7
15	8	.171	507	220	30.4
15	3/16	.187	555	240	34.0
15	1/4	.250	739	320	45.5
16	16	.062	173	75	12.8
16	14	.078	217	94	16.0
16	12	.109	303	131	21.5
16	10	.140	388	168	27.3
16	8	.171	475	206	33.3
16	3/16	.187	520	225	36.0
16	1/4	.250	693	300	48.2
16	5/16	.312	866	375	60.6
18	16	.062	154	67	14.5
18	14	.078	193	84	17.8
18	12	.109	270	117	24.4
18	10	.140	346	150	30.7
18	8	.171	422	183	38.4
18	3/16	.187	462	200	40.5
18	1/4	.250	616	267	54.1
18	5/16	.312	770	333	67.7
18	3/8	.375	924	400	81.3
20	16	.062	139	60	16.0
20	14	.078	173	75	19.6
20	12	.109	242	105	27.3
20	10	.140	311	135	34.5
20	8	.171	380	165	41.5
20	3/16	.187	416	180	45.0
20	1/4	.250	555	240	59.6
20	5/16	.312	693	300	74.6
20	3/8	.375	831	360	89.5
20	7/16	.437	970	420	105.0
22	16	.062	126	55	17.7
22	14	.078	157	68	21.2
22	12	.109	220	95	29.2
22	10	.140	283	123	37.1
22	8	.171	346	150	45.2
22	3/16	.187	378	164	49.0
22	1/4	.250	505	219	65.5
22	5/16	.312	631	273	81.5
22	3/8	.375	757	328	98.0
22	7/16	.437	883	383	114.5
22	1/2	.500	1008	437	131.0
24	14	.078	144	63	23.7
24	12	.109	202	88	32.5
24	10	.140	259	112	40.5
24	8	.171	317	137	49.2
24	3/16	.187	346	150	53.0
24	1/4	.250	462	200	71.0
24	5/16	.312	578	250	88.5
24	3/8	.375	693	300	106.0
24	7/16	.437	808	350	124.5
24	1/2	.500	924	400	142.0
26	14	.078	133	58	25.5
26	12	.109	186	81	34.5
26	10	.140	239	104	43.7
26	8	.171	293	127	53.0
26	3/16	.187	320	139	57.5
26	1/4	.250	427	185	76.5

Internal Diam.	Thickness of Plate		Safe Head	Safe Pressure	Weight per lin. ft.
Ins.	U.S. St'd G'ge	Ins.	Ft.	lbs Sq. In.	lbs
26	5/16	.312	533	231	95.5
26	3/8	.375	640	278	114.5
26	7/16	.437	747	324	134.0
26	1/2	.500	854	370	153.0
26	5/8	.625	1066	462	191.0
28	14	.078	124	54	27.2
28	12	.109	173	75	37.5
28	10	.140	222	96	47.5
28	8	.171	272	118	58.0
28	3/16	.187	297	129	62.0
28	1/4	.250	396	172	82.2
28	5/16	.437	496	215	102.5
28	3/8	.375	595	258	123.0
28	7/16	.437	695	301	143.5
28	1/2	.500	794	344	164.0
28	5/8	.625	993	430	205.0
30	12	.109	162	70	39.5
30	10	.140	208	90	50.3
30	8	.171	254	110	60.5
30	3/16	.187	277	120	65.5
30	1/4	.250	370	160	87.5
30	5/16	.312	462	200	109.0
30	3/8	.375	555	240	130.5
30	7/16	.437	647	280	151.5
30	1/2	.500	739	320	174.5
30	5/8	.625	924	400	220.0
30	3/4	.750	1108	480	264.0
36	12	.109	134	58	47.7
36	10	.140	173	75	60.0
36	8	.171	211	92	75.0
36	3/16	.187	231	100	79.0
36	1/4	.250	308	133	105.5
36	5/16	.312	385	167	130.0
36	3/8	.375	462	200	156.0
36	7/16	.437	539	233	182.5
36	1/2	.500	616	267	207.0
36	5/8	.625	770	333	260.0
36	3/4	.750	924	400	312.5
36	7/8	.875	1078	467	366.0
36	1 in.	1.000	1232	533	420.0
40	10	.140	155	67	67.5
40	8	.171	190	82	81.0
40	3/16	.187	208	90	88.0
40	1/4	.250	277	120	116.0
40	5/16	.312	346	150	141.0
40	3/8	.375	416	180	172.5
40	7/16	.437	485	210	201.5
40	1/2	.500	555	240	229.5
40	5/8	.625	693	300	288.0
40	3/4	.750	831	360	345.5
40	7/8	.875	970	420	405.0
40	1 in.	1.000	1110	480	461.5
42	10	.140	148	64	69.5
42	8	.171	181	78	84.7
42	3/16	.187	198	86	91.5
42	1/4	.250	264	114	122.0
42	5/16	.312	330	143	151.0
42	3/8	.375	396	172	180.5
42	7/16	.437	462	200	211.0

Internal Diam.	Thickness of Plate		Safe Head	Safe Pressure	Weight per lin. ft.
Ins.	U.S. St'd G'ge	Ins.	Ft	lbs Sq. In.	lbs
42	1/2	.500	528	229	240.5
42	5/8	.625	660	286	302.0
42	3/4	.750	792	343	361.5
42	7/8	.875	924	400	424.0
42	1 in.	1.000	1056	458	486.0
48	10	.140	130	56	80.5
48	8	.171	158	69	98.0
48	3/16	187	173	75	106.0
48	1/4	.250	231	100	142.0
48	5/16	.312	289	125	177.0
48	3/8	.375	346	150	212.0
48	7/16	.437	404	175	249.0
48	1/2	.500	462	200	284.0
48	5/8	.625	578	250	354.0
48	3/4	.750	693	300	430.0
48	7/8	.875	808	350	505.0
48	1 in.	1.000	924	400	582.0
54	8	.171	141	61	110.0
54	3/16	.187	154	67	119.0
54	1/4	.250	205	89	159.0
54	5/16	.312	256	111	198.0
54	3/8	.375	308	133	237.0
54	7/16	.437	359	156	277.5
54	1/2	.500	411	178	316.5
54	5/8	.625	513	222	399.5
54	3/4	.750	616	267	479.5
54	7/8	.875	719	312	563.5
54	1 in.	1.000	822	356	647.5
60	8	.171	127	55	121.0
60	3/16	.187	139	60	131.0
60	1/4	.250	185	80	175.0
60	5/16	.312	231	100	218.0
60	3/8	.375	277	120	261.0
60	7/16	.437	323	140	303.0
60	1/2	.500	370	160	349.0
60	5/8	.625	462	200	440.0
60	3/4	.750	555	240	528.0
60	7/8	.875	647	280	620.0
60	1 in.	1.000	739	320	712.0
66	3/16	.187	127	55	144.5
66	1/4	.250	168	73	193.0
66	5/16	.312	210	91	239.0
66	3/8	.375	252	109	286.5
66	7/16	.437	294	128	334.0
66	1/2	.500	336	146	382.0
66	5/8	.625	420	182	480.0
66	3/4	.750	504	218	577.5
66	7/8	.875	588	255	677.0
66	1 in.	1.000	672	292	777.5
72	3/16	.187	115	50	158.0
72	1/4	.250	154	67	211.0
72	5/16	.312	193	84	260.0
72	3/8	.375	231	100	312.0
72	7/16	.437	270	117	365.0
72	1/2	.500	308	133	414.0
72	5/8	.625	385	167	520.0
72	3/4	.750	462	200	624.0
72	7/8	.875	539	233	732.0
72	1 in.	1.000	616	267	840.0

CIRCUMFERENCES AND AREAS OF CIRCLES

FROM 1/64 TO 100

Diam.	Circum.	Area
1/64	.04909	.00019
1/32	.09818	.00077
3/64	.14726	.00173
1/16	.19635	.00307
3/32	.29452	.00690
1/8	.39270	.01227
5/32	.49087	.01917
3/16	.58905	.02761
7/32	.68722	.03758
1/4	.78540	.04909
9/32	.88357	.06213
5/16	.98175	.07670
11/32	1.0799	.09281
3/8	1.1781	.11045
13/32	1.2763	.12962
7/16	1.3744	.15033
15/32	1.4726	.17257
1/2	1.5708	.19635
17/32	1.6690	.22166
9/16	1.7671	.24850
19/32	1.8653	.27688
5/8	1.9635	.30680
21/32	2.0617	.33824
11/16	2.1598	.37122
23/32	2.2580	.40574
3/4	2.3562	.44179
25/32	2.4544	.47937
13/16	2.5525	.51849
27/32	2.6507	.55914
7/8	2.7489	.60132
29/32	2.8471	.64504
15/16	2.9452	.69029
31/32	3.0434	.73708
1	3.1416	.7854
1/16	3.3379	.8866
1/8	3.5343	.9940
3/16	3.7306	1.1075
1/4	3.9270	1.2272
5/16	4.1233	1.3530
3/8	4.3197	1.4849
7/16	4.5160	1.6230
1/2	4.7124	1.7671
9/16	4.9087	1.9175
5/8	5.1051	2.0739
11/16	5.3014	2.2365
3/4	5.4978	2.4053
13/16	5.6941	2.5802
7/8	5.8905	2.7612
15/16	6.0868	2.9483
2	6.2832	3.1416
1/16	6.4795	3.3410
1/8	6.6759	3.5466
3/16	6.8722	3.7583
1/4	7.0686	3.9761
5/16	7.2649	4.2000

Diam.	Circum.	Area
2 3/8	7.4613	4.4301
7/16	7.6576	4.6664
1/2	7.8540	4.9087
9/16	8.0503	5.1572
5/8	8.2467	5.4119
11/16	8.4430	5.6727
3/4	8.6394	5.9396
13/16	8.8357	6.2126
7/8	9.0321	6.4918
15/16	9.2284	6.7771
3	9.4248	7.0686
1/16	9.6211	7.3662
1/8	9.8175	7.6699
3/16	10.014	7.9798
1/4	10.210	8.2958
5/16	10.407	8.6179
3/8	10.603	8.9462
7/16	10.799	9.2806
1/2	10.996	9.6211
9/16	11.192	9.9678
5/8	11.388	10.321
11/16	11.585	10.680
3/4	11.781	11.045
13/16	11.977	11.416
7/8	12.174	11.793
15/16	12.370	12.177
4	12.566	12.566
1/16	12.763	12.962
1/8	12.959	13.364
3/16	13.155	13.772
1/4	13.352	14.186
5/16	13.548	14.607
3/8	13.744	15.033
7/16	13.941	15.466
1/2	14.137	15.904
9/16	14.334	16.349
5/8	14.530	16.800
11/16	14.726	17.257
3/4	14.923	17.728
13/16	15.119	18.190
7/8	15.315	18.665
15/16	15.512	19.147
5	15.708	19.635
1/16	15.904	20.129
1/8	16.101	20.629
3/16	16.297	21.135
1/4	16.493	21.648
5/16	16.690	22.166
3/8	16.886	22.691
7/16	17 082	23.221
1/2	17.279	23.758
9/16	17.475	24.301
5/8	17.671	24.850
11/16	17.868	25.406
3/4	18.064	25.967
13/16	18.261	26.535
7/8	18.457	27.109
15/16	18.653	27.688

Diam.	Circum.	Area
6	18.850	28.274
1/8	19.242	29.465
1/4	19.635	30.680
3/8	20.028	31.919
1/2	20.420	33.183
5/8	20.813	34.472
3/4	21.206	35.785
7/8	21.598	37.122
7	21.991	38.485
1/8	22.384	39.871
1/4	22.776	41.282
3/8	23.169	42.718
1/2	23.562	44.179
5/8	23.955	45.664
3/4	24 347	47.173
7/8	24.740	48.707
8	25.133	50.265
1/8	25.525	51.849
1/4	25.918	53.456
3/8	26.311	55.088
1/2	26.704	56.745
5/8	27.096	58.426
3/4	27.489	60.132
7/8	27.882	61.862
9	28.274	63.617
1/8	28.667	65.397
1/4	29.060	67.201
3/8	29.452	69.029
1/2	29.845	70.882
5/8	30.238	72.760
3/4	30.631	74.662
7/8	31.023	76.589
10	31.416	78.540
1/8	31.809	80.516
1/4	32.201	82.516
3/8	32.594	84.541
1/2	32.987	86.590
5/8	33.379	88.664
3/4	33.772	90.763
7/8	34.165	92.886
11	34.558	95.033
1/8	34.950	97.205
1/4	35.343	99.402
3/8	35.736	101.62
1/2	36.128	103.87
5/8	36.521	106.14
3/4	36.914	108.43
7/8	37.306	110.75
12	37.699	113.10
1/8	38.092	115.47
1/4	38.485	117.86
3/8	38.877	120.28
1/2	39.270	122.72
5/8	39.663	125.19
3/4	40.055	127.68
7/8	40.448	130.19
13	40.841	132.73
1/8	41.233	135.30

Diam.	Circum.	Area	Diam.	Circum.	Area	Diam.	Circum.	Area
13 1/4	41.626	137.89	21 1/8	66.366	350.50	29	91.106	660.52
3/8	42.019	140.50	1/4	66.759	354.66	1/8	91.499	666.23
1/2	42.412	143.14	3/8	67.152	358.84	1/4	91.892	671.96
5/8	42.804	145.80	1/2	67.544	363.05	3/8	92.284	677.71
3/4	43.197	148.49	5/8	67.937	367.28	1/2	92.677	683.49
7/8	43.590	151.20	3/4	68.330	371.54	5/8	93.070	689.30
14	43.982	153.94	7/8	68.722	375.83	3/4	93.462	695.13
1/8	44.375	156.70	22	69.115	380.13	7/8	93.855	700.98
1/4	44.768	159.48	1/8	69.508	384.46	30	94.248	706.86
3/8	45.160	162.30	1/4	69.900	388.82	1/8	94.640	712.76
1/2	45.553	165.13	3/8	70.293	393.20	1/4	95.033	718.69
5/8	45.946	167.99	1/2	70.686	397.61	3/8	95.426	724.64
3/4	46.338	170.87	5/8	71.079	402.04	1/2	95.819	730.62
7/8	46.731	173.78	3/4	71.471	406.49	5/8	96.211	736.62
15	47.124	176.71	7/8	71.864	410.97	3/4	96.604	742.64
1/8	47.517	179.67	23	72.257	415.48	7/8	96.997	748.69
1/4	47.909	182.65	1/8	72.649	420.00	31	97.389	754.77
3/8	48.302	185.66	1/4	73.042	424.56	1/8	97.782	760.87
1/2	48.695	188.69	3/8	73.435	429.13	1/4	98.175	766.99
5/8	49.087	191.75	1/2	73.827	433.74	3/8	98.567	773.14
3/4	49.480	194.83	5/8	74.220	438.36	1/2	98.960	779.31
7/8	49.873	197.93	3/4	74.613	443.01	5/8	99.353	785.51
16	50.265	201.06	7/8	75.006	447.69	3/4	99.746	791.73
1/8	50.658	204.22	24	75.398	452.39	7/8	100.138	797.98
1/4	51.051	207.39	1/8	75.791	457.11	32	100.531	804.25
3/8	51.444	210.60	1/4	76.184	461.86	1/8	100.924	810.54
1/2	51.836	213.82	3/8	76.576	466.64	1/4	101.316	816.86
5/8	52.229	217.08	1/2	76.969	471.44	3/8	101.709	823.21
3/4	52.622	220.35	5/8	77.362	476.26	1/2	102.102	829.58
7/8	53.014	223.65	3/4	77.754	481.11	5/8	102.494	835.97
17	53.407	226.98	7/8	78.147	485.98	3/4	102.887	842.39
1/8	53.800	230.33	25	78.540	490.87	7/8	103.280	848.83
1/4	54.192	233.71	1/8	78.933	495.79	33	103.673	855.30
3/8	54.585	237.10	1/4	79.325	500.74	1/8	104.065	861.79
1/2	54.978	240.53	3/8	79.718	505.71	1/4	104.458	868.31
5/8	55.371	243.98	1/2	80.111	510.71	3/8	104.851	874.85
3/4	55.763	247.45	5/8	80.503	515.72	1/2	105.243	881.41
7/8	56.156	250.95	3/4	80.896	520.77	5/8	105.636	888.00
18	56.549	254.47	7/8	81.289	525.84	3/4	106.029	894.62
1/8	56.941	258.02	26	81.681	530.93	7/8	106.421	901.26
1/4	57.334	261.59	1/8	82.074	536.05	34	106.814	907.92
3/8	57.727	265.18	1/4	82.467	541.19	1/8	107.207	914.61
1/2	58.119	268.80	3/8	82.860	546.35	1/4	107.600	921.32
5/8	58.512	272.45	1/2	83.252	551.55	3/8	107.992	928.06
3/4	58.905	276.12	5/8	83.645	556.76	1/2	108.385	934.82
7/8	59.298	279.81	3/4	84.038	562.00	5/8	108.778	941.61
19	59.690	283.53	7/8	84.430	567.27	3/4	109.170	948.42
1/8	60.083	287.27	27	84.823	572.56	7/8	109.563	955.25
1/4	60.476	291.04	1/8	85.216	577.87	35	109.956	962.11
3/8	60.868	294.83	1/4	85.608	583.21	1/8	110.348	969.00
1/2	61.261	298.65	3/8	86.001	588.57	1/4	110.741	975.91
5/8	61.654	302.49	1/2	86.394	593.96	3/8	111.134	982.84
3/4	62.046	306.35	5/8	86.786	599.37	1/2	111.527	989.80
7/8	62.439	310.24	3/4	87.179	604.81	5/8	111.919	996.78
20	62.832	314.16	7/8	87.572	610.27	3/4	112.312	1003.8
1/8	63.225	318.10	28	87.965	615.75	7/8	112.705	1010.8
1/4	63.617	322.06	1/8	88.357	621.26	36	113.097	1017.9
3/8	64.010	326.05	1/4	88.750	626.80	1/8	113.490	1025.0
1/2	64.403	330.06	3/8	89.143	632.36	1/4	113.883	1032.1
5/8	64.795	334.10	1/2	89.535	637.94	3/8	114.275	1039.2
3/4	65.188	338.16	5/8	89.928	643.55	1/2	114.668	1046.3
7/8	65.581	342.25	3/4	90.321	649.18	5/8	115.061	1053.5
21	65.973	346.36	7/8	90.713	654.84	3/4	115.454	1060.7

Diam.	Circum.	Area	Diam.	Circum.	Area	Diam.	Circum.	Area
36 7/8	115.846	1068.0	44 3/4	140.586	1572.8	52 5/8	165.326	2175.1
37	116.239	1075.2	7/8	140.979	1581.6	3/4	165.719	2185.4
1/8	116.632	1082.5	45	141.372	1590.4	7/8	166.112	2195.8
1/4	117.024	1089.8	1/8	141.764	1599.3	53	166.504	2206.2
3/8	117.417	1097.1	1/4	142.157	1608.2	1/8	166.897	2216.6
1/2	117.810	1104.5	3/8	142.550	1617.0	1/4	167.290	2227.0
5/8	118.202	1111.8	1/2	142.942	1626.0	3/8	167.683	2237.5
3/4	118.596	1119.2	5/8	143.335	1634.9	1/2	168.075	2248.0
7/8	118.988	1126.7	3/4	143.728	1643.9	5/8	168.468	2258.5
38	119.381	1134.1	7/8	144.121	1652.9	3/4	168.861	2269.1
1/8	119.773	1141.6	46	144.513	1661.9	7/8	169.253	2279.6
1/4	120.166	1149.1	1/8	144.906	1670.9	54	169.646	2290.2
3/8	120.559	1156.6	1/4	145.299	1680.0	1/8	170.039	2300.8
1/2	120.951	1164.2	3/8	145.691	1689.1	1/4	170.431	2311.5
5/8	121.344	1171.7	1/2	146.084	1698.2	3/8	170.824	2322.1
3/4	121.737	1179.3	5/8	146.477	1707.4	1/2	171.217	2332.8
7/8	122.129	1186.9	3/4	146.869	1716.5	5/8	171.609	2343.5
39	122.522	1194.6	7/8	147.262	1725.7	3/4	172.002	2354.3
1/8	122.915	1202.3	47	147.655	1734.9	7/8	172.395	2365.0
1/4	123.308	1210.0	1/8	148.048	1744.2	55	172.788	2375.8
3/8	123.700	1217.7	1/4	148.440	1753.5	1/8	173.180	2386.6
1/2	124.093	1225.4	3/8	148.833	1762.7	1/4	173.573	2397.5
5/8	124.486	1233.2	1/2	149.226	1772.1	3/8	173.966	2408.3
3/4	124.878	1241.0	5/8	149.618	1781.4	1/2	174.358	2419.2
7/8	125.271	1248.8	3/4	150.011	1790.8	5/8	174.751	2430.1
40	125.664	1256.6	7/8	150.404	1800.1	3/4	175.144	2441.1
1/8	126.056	1264.5	48	150.796	1809.6	7/8	175.536	2452.0
1/4	126.449	1272.4	1/8	151.189	1819.0	56	175.929	2463.0
3/8	126.842	1280.3	1/4	151.582	1828.5	1/8	176.322	2474.0
1/2	127.235	1288.2	3/8	151.975	1837.9	1/4	176.715	2485.0
5/8	127.627	1296.2	1/2	152.367	1847.5	3/8	177.107	2496.1
3/4	128.020	1304.2	5/8	152.760	1857.0	1/2	177.500	2507.2
7/8	128.413	1312.2	3/4	153.153	1866.5	5/8	177.893	2518.3
41	128 805	1320.3	7/8	153.545	1876.1	3/4	178.285	2529.4
1/8	129.198	1328.3	49	153.938	1885.7	7/8	178.678	2540.6
1/4	129.591	1336.4	1/8	154.331	1895.4	57	179.071	2551.8
3/8	129.983	1344.5	1/4	154.723	1905.0	1/8	179.463	2563.0
1/2	130.376	1352.7	3/8	155.116	1914.7	1/4	179.856	2574.2
5/8	130.769	1360.8	1/2	155.509	1924.4	3/8	180.249	2585.4
3/4	131.161	1369.0	5/8	155.902	1934.2	1/2	180.642	2596.7
7/8	131 554	1377.2	3/4	156.294	1943.9	5/8	181.034	2608.0
42	131.947	1385.4	7/8	156.687	1953.7	3/4	181.427	2619.4
1/8	132.340	1393.7	50	157.080	1963.5	7/8	181.820	2630.7
1/4	132.732	1402.0	1/8	157.472	1973.3	58	182.212	2642.1
3/8	133.125	1410.3	1/4	157.865	1983.2	1/8	182.605	2653.5
1/2	133.518	1418.6	3/8	158.258	1993.1	1/4	182.998	2664.9
5/8	133.910	1427.0	1/2	158.650	2003.0	3/8	183 390	2676.4
3/4	134.303	1435.4	5/8	159.043	2012.9	1/2	183.783	2687.8
7/8	134.696	1443.8	3/4	159.436	2022.8	5/8	184.176	2699.3
43	135.088	1452.2	7/8	159.829	2032.8	3/4	184.569	2710.9
1/8	135.481	1460.7	51	160.221	2042.8	7/8	184 961	2722.4
1/4	135.874	1469.1	1/8	160.614	2052.8	59	185.354	2734.0
3/8	136.267	1477.6	1/4	161.007	2062.9	1/8	185.747	2745.6
1/2	136.659	1486.2	3/8	161.399	2073.0	1/4	186.139	2757.2
5/8	137.052	1494.7	1/2	161.792	2083.1	3/8	186.532	2768.8
3/4	137.445	1503.3	5/8	162.185	2093.2	1/2	186.925	2780.5
7/8	137.837	1511.9	3/4	162.577	2103.3	5/8	187.317	2792.2
44	138.230	1520.5	7/8	162.970	2113.5	3/4	187.710	2803.9
1/8	138.623	1529.2	52	163.363	2123.7	7/8	188.103	2815.7
1/4	139.015	1537.9	1/8	163.756	2133.9	60	188.496	2827.4
3/8	139.408	1546.6	1/4	164.148	2144.2	1/8	188.888	2839.2
1/2	139.801	1555.3	3/8	164.541	2154.5	1/4	189.281	2851.0
5/8	140.194	1564.0	1/2	164.934	2164.8	3/8	189.674	2862.9

Diam.	Circum.	Area	Diam.	Circum.	Area	Diam.	Circum.	Area
60 1/2	190.066	2874.8	68 3/8	214.806	3671.8	76 1/4	239.546	4566.4
5/8	190.459	2886.6	1/2	215.199	3685.3	3/8	239.939	4581.3
3/4	190.852	2898.6	5/8	215.592	3698.7	1/2	240.332	4596.3
7/8	191.244	2910.5	3/4	215.984	3712.2	5/8	240.725	4611.4
61	191.637	2922.5	7/8	216.377	3725.7	3/4	241.117	4626.4
1/8	192.030	2934.5	69	216.770	3739.3	7/8	241.510	4641.5
1/4	192.423	2946.5	1/8	217.163	3752.8	77	241.903	4656.6
3/8	192 815	2958.5	1/4	217.555	3766.4	1/8	242.295	4671.8
1/2	193.208	2970.6	3/8	217.948	3780.0	1/4	242.688	4686.9
5/8	193.601	2982.7	1/2	218.341	3793.7	3/8	243.081	4702.1
3/4	193.993	2994.8	5/8	218.733	3807.3	1/2	243.473	4717.3
7/8	194.386	3006.9	3/4	219.126	3821.0	5/8	243.866	4732.5
62	194.779	3019.1	7/8	219.519	3834.7	3/4	244.259	4747.8
1/8	195.171	3031.3	70	219.911	3848.5	7/8	244.652	4763.1
1/4	195.564	3043.5	1/8	220.304	3862.2	78	245.044	4778.4
3/8	195.957	3055.7	1/4	220.697	3876.0	1/8	245.437	4793.7
1/2	196.350	3068.0	3/8	221.090	3889.8	1/4	245.830	4809.0
5/8	196.742	3080.3	1/2	221.482	3903.6	3/8	246.222	4824.4
3/4	197.135	3092.6	5/8	221.875	3917.5	1/2	246.615	4839.8
7/8	197.528	3104.9	3/4	222.268	3931.4	5/8	247.008	4855.2
63	197.920	3117.2	7/8	222.660	3945.3	3/4	247.400	4870.7
1/8	198.313	3129.6	71	223.053	3959.2	7/8	247.793	4886.2
1/4	198.706	3142.0	1/8	223.446	3973.1	79	248.186	4901.7
3/8	199.098	3154.5	1/4	223.838	3987.1	1/8	248.579	4917.2
1/2	199.491	3166.9	3/8	224.231	4001.1	1/4	248.971	4932.7
5/8	199.884	3179.4	1/2	224.624	4015.2	3/8	249.364	4948.3
3/4	200.277	3191.9	5/8	225.017	4029.2	1/2	249.757	4963.9
7/8	200.669	3204.4	3/4	225.409	4043.3	5/8	250.149	4979.5
64	201.062	3217.0	7/8	225.802	4057.4	3/4	250.542	4995.2
1/8	201.455	3229.6	72	226.195	4071.5	7/8	250.935	5010.9
1/4	201.847	3242.2	1/8	226.587	4085.7	80	251.327	5026.5
3/8	202.240	3254.8	1/4	226.980	4099.8	1/8	251.720	5042.3
1/2	202.633	3267.5	3/8	227.373	4114.0	1/4	252.113	5058.0
5/8	203.025	3280.1	1/2	227.765	4128.2	3/8	252.506	5073.8
3/4	203.418	3292.8	5/8	228.158	4142 5	1/2	252.898	5089.6
7/8	203.811	3305.6	3/4	228.551	4156.8	5/8	253.291	5105.4
65	204.204	3318.3	7/8	228.944	4171.1	3/4	253.684	5121.2
1/8	204.596	3331.1	73	229.336	4185.4	7/8	254.076	5137.1
1/4	204.989	3343.9	1/8	229.729	4199.7	81	254.469	5153.0
3/8	205.382	3356.7	1/4	230.122	4214.1	1/8	254.862	5168.9
1/2	205.774	3369.6	3/8	230.514	4228.5	1/4	255.254	5184.9
5/8	206.167	3382.4	1/2	230.907	4242.9	3/8	255.647	5200.8
3/4	206.560	3395.3	5/8	231.300	4257.4	1/2	256.040	5216.8
7/8	206.952	3408.2	3/4	231.692	4271.8	5/8	256.433	5232.8
66	207.345	3421.2	7/8	232.085	4286.3	3/4	256.825	5248.9
1/8	207.738	3434.2	74	232.478	4300.8	7/8	257.218	5264.9
1/4	208.131	3447.2	1/8	232.871	4315.4	82	257.611	5281.0
3/8	208.523	3460.2	1/4	233.263	4329.9	1/8	258.003	5297.1
1/2	208.916	3473 2	3/8	233.656	4344.5	1/4	258.396	5313.3
5/8	209.309	3486.3	1/2	234.049	4359.2	3/8	258.789	5329.4
3/4	209.701	3499.4	5/8	234.441	4373.8	1/2	259.181	5345.6
7/8	210.094	3512 5	3/4	234.834	4388.5	5/8	259.574	5361.8
67	210.487	3525.7	7/8	235.227	4403.1	3/4	259.967	5378.1
1/8	210.879	3538.8	75	235.619	4417.9	7/8	260.359	5394.3
1/4	211.272	3552.0	1/8	236.012	4432.6	83	260.752	5410.6
3/8	211.665	3565.2	1/4	236.405	4447.4	1/8	261.145	5426.9
1/2	212.058	3578.5	3/8	236.798	4462.2	1/4	261.538	5443.3
5/8	212.450	3591.7	1/2	237.190	4477.0	3/8	261.930	5459.6
3/4	212.843	3605.0	5/8	237.583	4491.8	1/2	262.323	5476.0
7/8	213.236	3618.3	3/4	237.976	4506.7	5/8	262.716	5492.4
68	213.628	3631.7	7/8	238.368	4521.5	3/4	263.108	5508.8
1/8	214.021	3645.0	76	238.761	4536.5	7/8	263.501	5525.3
1/4	214.414	3658.4	1/8	239.154	4551.4	84	263.894	5541.8

Diam.	Circum.	Area	Diam.	Circum.	Area	Diam.	Circum.	Area
84 ⅛	264.286	5558.3	89 ½	281.173	6291.2	94 ⅞	298.059	7069.6
¼	264.679	5574.8	⅝	281.565	6308.8	95	298.451	7088.2
⅜	265.072	5591.4	¾	281.958	6326.4	⅛	298.844	7106.9
½	265.465	5607.9	⅞	282.351	6344.1	¼	299.237	7125.6
⅝	265.857	5624.5	90	282.743	6361.7	⅜	299.629	7144.3
¾	266.250	5641.2	⅛	283.136	6379.4	½	300.022	7163.0
⅞	266.643	5657.8	¼	283.529	6397.1	⅝	300.415	7181.8
85	267.035	5674 5	⅜	283.921	6414.9	¾	300.807	7200.6
⅛	267.428	5691.2	½	284.314	6432.6	⅞	301.200	7219.4
¼	267.821	5707.9	⅝	284.707	6450.4	96	301.593	7238.2
⅜	268.213	5724.7	¾	285.100	6468.2	⅛	301.986	7257.1
½	268.606	5741.5	⅞	285.492	6486.0	¼	302.378	7276.0
⅝	268.999	5758.3	91	285.885	6503.9	⅜	302.771	7294.9
¾	269.392	5775.1	⅛	286.278	6521.8	½	303.164	7313.8
⅞	269.784	5791.9	¼	286.670	6539.7	⅝	303.556	7332.8
86	270.177	5808.8	⅜	287.063	6557.6	¾	303.949	7351.8
⅛	270.570	5825.7	½	287.456	6575.5	⅞	304.342	7370.8
¼	270.962	5842.6	⅝	287.848	6593.5	97	304.734	7389.8
⅜	271.355	5859.6	¾	288.241	6611.5	⅛	305.127	7408.9
½	271.748	5876.5	⅞	288.634	6629.6	¼	305.520	7428.0
⅝	272.140	5893.5	92	289.027	6647.6	⅜	305 913	7447.1
¾	272.533	5910.6	⅛	289.419	6665.7	½	306.305	7466.2
⅞	272.926	5927.6	¼	289.812	6683.8	⅝	306.698	7485.3
87	273.319	5944.7	⅜	290.205	6701.9	¾	307.091	7504.5
⅛	273.711	5961.8	½	290.597	6720.1	⅞	307.483	7523.7
¼	274.104	5978.9	⅝	290.990	6738.2	98	307.876	7543.0
⅜	274.497	5996.0	¾	291.383	6756.4	⅛	308.269	7562.2
½	274.889	6013.2	⅞	291.775	6774.7	¼	308.661	7581.5
⅝	275.282	6030.4	93	292.168	6792.9	⅜	309.054	7600.8
¾	275.675	6047.6	⅛	292.561	6811.2	½	309.447	7620.1
⅞	276.067	6064.9	¼	292.954	6829.5	⅝	309.840	7639.5
88	276.460	6082.1	⅜	293.346	6847.8	¾	310.232	7658.9
⅛	276.853	6099.4	½	293.739	6866.1	⅞	310.625	7678.3
¼	277.246	6116.7	⅝	294.132	6884.5	99	311.018	7697.7
⅜	277.638	6134.1	¾	294.524	6902.9	⅛	311.410	7717.1
½	278.031	6151.4	⅞	294.917	6921.3	¼	311.803	7736.6
⅝	278.424	6168.8	94	295.310	6939.8	⅜	312.196	7756.1
¾	278.816	6186.2	⅛	295.702	6958.2	½	312.588	7775.6
⅞	279.209	6203.7	¼	296.095	6976 7	⅝	312.981	7795.2
89	279.602	6221.1	⅜	296.488	6995.3	¾	313.374	7814.8
⅛	279.994	6238.6	½	296.881	7013.8	⅞	313.767	7834.4
¼	280.387	6256.1	⅝	297.273	7032.4	100	314.159	7854.0
⅜	280.780	6273.7	¾	297.666	7051.0			

STRENGTH OF WROUGHT IRON BOLTS

Computed by A. F. Nagle—(Kent)

Diameter of Bolt, Inches	Number of Threads	Diameter of Bottom of Thread, Inches	Area at Bottom of Thread, Square Inches	Stress Upon Bolt Upon Basis of					
				3000 Lbs. per Sq. Inch Lbs.	4000 Lbs. per Sq. Inch Lbs.	5000 Lbs. per Sq. Inch Lbs.	7000 Lbs per Sq. Inch Lbs.	10000 Lbs. per Sq. Inch Lbs.	Probable Breaking Load Lbs.
½	13	.38	.12	350	460	580	810	1160	5800
9/16	12	.44	.15	450	600	750	1050	1500	7500
⅝	11	.49	.19	560	750	930	1310	1870	9000
¾	10	.60	.28	750	1130	1410	1980	2830	14000
⅞	9	.71	.39	1180	1570	1970	2760	3940	19000
1	8	.81	.52	1550	2070	2600	3630	5180	25000
1⅛	7	.91	.65	1950	2600	3250	4560	6510	30000
1¼	7	1.04	.84	2520	3360	4200	5900	8410	39000
1⅜	6	1.12	1.00	3000	4000	5000	7000	10000	46000
1½	6	1.25	1.23	3680	4910	6140	8600	12280	56000
1⅝	5½	1.35	1.41	4300	5740	7180	10000	14360	65000
1¾	5	1.45	1.65	4950	6600	8250	11560	16510	74000
1⅞	5	1.57	1.95	5840	7800	9800	13640	19500	85000
2	4½	1.66	2.18	6540	8720	10900	15260	21800	95000
2¼	4½	1.92	2.88	8650	11530	14400	20180	28800	125000
2½	4	2.12	3.55	10640	14200	17730	24830	35500	150000
2¾	4	2.37	4.43	13290	17720	22150	31000	44300	186000
3	3½	2.57	5.20	15580	20770	26000	36360	52000	213000

DECIMAL EQUIVALENTS

DECIMAL EQUIVALENTS OF FRACTIONS OF 1 INCH FOR EACH 1/64

Fraction	1/32	1/64	Decimals of an Inch	Fraction	1/32	1/64	Decimals of an Inch
		1	.015 625			33	.515 625
	1		.031 250		17		.531 250
		3	.046 875			35	.546 875
1/16			.062 500	9/16			.562 500
		5	.078 125			37	.578 125
	3		.093 750		19		.593 750
		7	.109 375			39	.609 375
1/8			.125 000	5/8			.625 000
		9	.140 625			41	.640 625
	5		.156 250		21		.656 250
		11	.171 875			43	.671 875
3/16			.187 500	11/16			.687 500
		13	.203 125			45	.703 125
	7		.218 750		23		.718 750
		15	.234 375			47	.734 375
1/4			.250 000	3/4			.750 000
		17	.265 625			49	.765 625
	9		.281 250		25		.781 250
		19	.296 875			51	.796 875
5/16			.312 500	13/16			.812 500
		21	.328 125			53	.828 125
	11		.343 750		27		.843 750
		23	.359 375			55	.859 375
3/8			.375 000	7/8			.875 000
		25	.390 625			57	.890 625
	13		.406 250		29		.906 250
		27	.421 875			59	.921 875
7/16			.437 500	15/16			.937 500
		29	.453 125			61	.953 125
	15		.468 750		31		.968 750
		31	.484 375			63	.984 375
1/2			.500 000	1			1.000 000

DECIMALS OF A FOOT EQUIVALENT TO INCHES AND FRACTIONS OF AN INCH

Inches	0	1/8	1/4	3/8	1/2	5/8	3/4	7/8
0	.0000	.01042	.02083	.03125	.04166	.05208	.06250	.07292
1	.0833	.0937	.1042	.1146	.1250	.1354	.1459	.1563
2	.1667	.1771	.1875	.1979	.2083	.2188	.2292	.2396
3	.2500	.2604	.2708	.2813	.2917	.3021	.3125	.3229
4	.3333	.3437	.3542	.3646	.3750	.3854	.3958	.4063
5	.4167	.4271	.4375	.4479	.4583	.4688	.4792	.4896
6	.5000	.5104	.5208	.5313	.5417	.5521	.5625	.5729
7	.5833	.5937	.6042	.6146	.6250	.6354	.6459	.6563
8	.6667	.6771	.6875	.6979	.7083	.7188	.7292	.7396
9	.7500	.7604	.7708	.7813	.7917	.8021	.8125	.8229
10	.8333	.8437	.8542	.8646	.8750	.8854	.8958	.9063
11	.9167	.9271	.9375	.9479	.9583	.9688	.9792	.9896

USEFUL HYDRAULIC INFORMATION

In the **hydraulic formulae** given in the following notes, unless otherwise expressly stated, let

H = Head of water, expressed in feet;
P = Pressure of water, in pounds per square inch;
D = Diameter in feet or
d = Diameter in inches;
A = Area in square feet or
a = Area in square inches;
Q = Quantity in cubic feet per second;
T = Time in seconds;
V = Velocity in feet per second.

The following computations are based on an average temperature of 50° F., and an average latitude of 38°, as for California.

Atmospheric pressure is usually reckoned at 14.7 pounds per square inch. Theoretically, it is equivalent to the pressure of a column of water 33.91 feet high, or each 2.307 feet in height is equivalent to 1 pound pressure, or each foot in height is equivalent to a pressure of 0.4334 pound per square inch. Therefore

Pressure of water (P) = 0.4334 x Head of water.
Head of water (H) = 2.307 x Pressure of water.

The **theoretical velocity of water** issuing from an orifice is the same as that which would be acquired by a body falling from the height of the head of water above the orifice. That is

$$V = \sqrt{2g \times H}$$

in which (H) is the head of water; (g) the acceleration due to gravity = 32.15; and (V) the velocity in feet per second. In practice, this theoretical velocity is not attained, owing to various resistances, but the principle should always be borne in mind. This formula is usually expressed

$$\text{Spouting Velocity} = 8.03 \sqrt{H}$$

The quantities of water discharged in equal times by the same aperture under different heads are proportional to the square roots of the corresponding heads, measurements being made from the center of the orifice.

Relation between **Area, Velocity** and **Discharge.**

Let Q = Quantity of water discharged (in cubic feet per second).
V = Mean velocity (in feet per second).
A = Area of cross section (in square feet).

$$\text{Then } Q = A \times V;\ V = \frac{Q}{A};\ A = \frac{Q}{V}$$

Kinetic energy (K), or foot pounds, stored in a column of water in a round pipe of any diameter (D) and of any length (L), when moving at any velocity (V) per second:

$$K = 0.78 \times D^2 \times L \times V^2$$

If (a) be the area of a jet, in square inches; (V) its velocity, in feet per second; and (W) the weight of a cubic foot of water, the **energy** in foot-pounds per second will be

$$K = \frac{W \times a \times V^2}{2g \times 144} =$$

$$\frac{W \times a \times V^2}{92.59} =$$

$$0.0108 \times W \times a \times V^2.$$

The total **horizontal pressure** against a wall or dam varies as the square of the height. If (H) be the height of the dam, and (W) the weight of a cubic foot of water, the pressure per foot-width will be $\frac{1}{2}$ WH^2, and its point of application will be two-thirds of the distance from the top. Substituting 62.408 pounds for (W), the formula becomes

$$\text{Pressure per foot-width} = 31.204\ H^2$$

or where (w) is the width of the dam or surface in feet,

$$\text{Total pressure} = 31.204\ h^2 \times w$$

The **theoretical horse-power** of a stream is determined by multiplying the available flow in cubic feet per minute by 62.408 pounds (weight of a cubic foot of water) and by the vertical head in feet, and dividing the product by 33,000 (number of foot-pounds per minute equal to one horse-power).

Thus the theoretical horse-power (HP) developed by any quantity (Q) of water in cubic feet per second falling through any head (H),

$$HP = \frac{62.408 \times Q \times H \times 60}{33000} = 0.1134\,Q \times H = \frac{Q \times H}{8.81}$$

The **theoretical quantity** (Q) of water which will develop any horsepower (HP), when falling through any head (H).

$$Q = \frac{8.81 \times HP}{H}$$

If the efficiency of the water wheel is 80 per cent the above formula becomes

$$Q = \frac{8.81 \times HP}{0.8 \times H} \text{ or approximately } \frac{11 \times HP}{H}$$

or, on the same efficiency basis

$$HP = \frac{Q \times H}{11} \text{ or, } Q \times H \times 0.09$$

A convenient rule for use in determining the **thickness of riveted steel** pipe for given pressures is as follows: Multiply the given pressure in pounds by the radius of the pipe in inches, and divide by 10,000. The result will give approximately the thickness of plate required in inches. For example: A pressure of 160 pounds in a 30-inch pipe would require

$$\frac{160 \times 15}{10{,}000} = 0.2400 \text{ inch thickness.}$$

The nearest commercial size of plate to this figure is ¼ inch which is the required thickness of plate to be used. Such a pipe woud be strained to about one-fourth of its ultimate or bursting strength.

For a given diameter of pipe and velocity of flow, the **loss of head due to friction** in a pipe increases directly with the length and with the roughness of the pipe.

For a given length of pipe and velocity of flow, the **loss of head due to friction** decreases approximately as the diameter of the pipe increases.

For a given diameter and length of pipe, the **loss of head due to friction** increases directly as the roughness of the pipe and the square of the velocity of flow.

In the above cases the loss of head due to friction is independent of the pressure or head of water in the pipe.

To find the **capacity of cylindrical tanks** or pipes in U. S. gallons—the dimensions being given in inches: Square the diameter, and multiply by the length and by 0.0034. Thus

Capacity in gallons $= \frac{0.7854\ d^2 \times l}{231} = 0.0034\ d^2 \times l$; where l is length of pipe in inches;

or, if the dimensions are given in feet

Capacity in gallons $= \frac{0.07854\ D^2 \times L}{0.13368} = 5.87\ D^2 \times L$; where L is length of pipe in feet.

The **capacity of pipes** increases with the square of their diameter; thus doubling the diameter increases the capacity four times.

Capacity of pipes: A pipe one yard long holds approximately as many pounds of water as the square of its diameter, in inches. Thus a 6-inch pipe holds approximately 36 pounds of water in each yard of length. For more accurate results add 2¼ per cent to this value.

USEFUL DATA

Acceleration due to gravity, for 38 degrees latitude = 32.15

$\sqrt{32.15}=8.03$

$\pi=3.1416$

$\frac{\pi}{4}=0.7854$

Circumference of a circle = diameter x 3.1416

Diameter of a circle = circumference x 0.3183

Area of a circle = square of diameter x 0.7854

Side of square with area equal to a circle = diameter of circle x 0.8862

Side of square inscribed in a circle = diameter of circle x 0.7071

Diameter of circle of area equal to a square = side of square x 1.128

Doubling the diameter of a circle increases its area four times.

Diameter of circle equal to a given area = square root of area x 1.128

Area of a rectangle = length multiplied by breadth.

Area of a triangle = base multiplied by ½ the altitude.

Area of a sector of a circle = ½ the length of the arc multiplied by the radius of the circle.

Surface of a sphere = square of diameter x 3.1416

Volume of a sphere = cube of diameter x 0.5236

Weight of cast iron, per cubic inch, 0.26 pound; of wrought iron, 0.278; of steel, 0.283; of copper and bronze, 0.32; of brass, 0.3

Steel is about two per cent heavier than wrought iron.

Cast iron is about six per cent lighter than wrought iron and about eight per cent lighter than steel.

Double riveting is from 18 per cent (for thin plates) to 28 per cent (for thick plates) stronger than single riveting.

Weight of round wrought iron per linear foot = square of diameter in quarter inches ÷ 6

Weight of flat wrought iron per linear foot = width in inches x thickness in inches x 10 ÷ 3; for more accurate results subtract 1.8 per cent of the weight.

Weight of flat wrought iron plates per square foot = approximately 5 pounds for each ⅛ inch thickness.

READY CONVERSION TABLES *

LINEAR MEASURES

1 inch =

0.083 333	foot
0.027 777 8	yard
0.000 015 78	mile
25.400 05	millimeters
2.540 005	centimeters
0.025 4	meter

1 foot =

12.	inches
0.333 333 33	yard
0.000 189 39	mile
30.480 1	centimeters
0.304 801	meter
0.000 304 8	kilometer

1 yard =

36.	inches
3.	feet
0.000 568 18	mile
91.440 2	centimeters
0.914 402	meter
0.000 914 40	kilometer

1 rod =

198.	inches
16.5	feet
5.5	yards
0.25	chain
0.003 125	mile
5.029 2	meters
0.005 029	kilometer

1 mile =

63,360.	inches
5,280.	feet
1,760.	yards
320.	rods
80.	chains
1,609.35	meters
1.609 35	kilometers
0.868 392	nautical mile or knot

1 link (surveyor's) =

7.92	inches
0.201 17	meter

1 chain (surveyor's) =

100.	links
66.	feet
20.117	meters
4.	rods
0.012 5	mile

1 millimeter =

0.039 37	inch
0.001	meter

1 centimeter =

0.393 70	inch
0.032 808 3	foot
0.01	meter

1 meter =

39.370 000	inches
3.280 83	feet
1.093 61	yards

1 kilometer =

3,280.83	feet
1,093.61	yards
0.621 370	mile

SURFACE MEASURES

1 square inch =

0.006 944 44	square foot
0.000 771 6	square yard
645.163	square millimeters
6.451 63	square centimeters

1 square foot =

144.	square inches
0.111 111	square yard
0.092 903 4	square meter

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* Based on the legal standard values of the United States Government. Ready Reference Tables, Vol. I, Conversion Factors, by Carl Hering.

SURFACE MEASURES—*Continued*

1 square yard =

1,296.	square inches
9.	square feet
0.836 126	square meter

1 acre =

43,560.	square feet
4,840.	square yards
208.710	feet square
0.001 562 50	square mile
4,046.87	square meters
0.404 687	hectare

1 square mile =

27,878,400.	square feet
640.	acres
1.	section
259.	hectares
2.590	square kilometers

1 square millimeter =

0.001 550	square inch

1 square centimeter =

0.115 0	square inch
0.001 076 387	square foot

1 square meter =

10.763 87	square feet
1.195 99	square yards
0.000 247 104	acre

1 hectare =

10,000.	square meters
107,638.7	square feet
2.471 04	acres
0.003 861	square mile

1 square kilometer =

100.	hectares
247.104	acres
0.386 101	square mile

MEASURES OF VOLUME AND CAPACITY

1 cubic inch =

16.387 16	cubic centimeters
0.017 316 0	quart (liquid)
0.004 329 00	U. S. gallons

1 cubic foot =

1,728.	cubic inches
29.922 1	quarts (liquid)
7.480 52	U. S. gallons "
0.037 037 0	cubic yard
0.028 317 0	cubic meter
28.317 0	liters

1 cubic yard =

46,656.	cubic inches
27.	cubic feet
807.896	quarts (liquid)
201.974	U. S. gallons
764.559	liters
0.764 559	cubic meter

1 U. S. gallon =

231.	cubic inches
0.133 681	cubic foot
0.832 702 4	English gallon (Imperial)
0.037 854 3	hectoliter
3.785 43	liters

1 English gallon (Imperial) =

277.410	cubic inches
1.200 91	U. S. gallons
4.545 963 1	liters

1 cubic centimeter =

0.061 023 4	cubic inch

1 cubic meter =

1,000.	liters
10.	hectoliters
264.17	U. S. gallons
35.314 5	cubic feet
1.307 94	cubic yards

1 liter =

1.	cubic decimeter
0.001	cubic meter
61.023 4	cubic inches
1.056 68	quarts (liquid)
0.264 170	U. S. gallon
0.035 314 5	cubic foot

1 hectoliter =

100.	liters
105.668	quarts (liquid)
3.531 45	cubic feet
26.417 0	U. S. gallons
0.130 794	cubic yard

WEIGHTS AND LENGTHS

1 pound per linear foot =

3.	pounds per yard
0.083 333 33	pound per inch
3.280 83	pounds per meter
1.488 16	kilograms per meter

1 pound per linear meter =

0.914 402	pound per yard
0.304 801	pound per foot
0.025 4	pound per inch

1 kilogram per linear meter =

2.015 91	pounds per yard
0.671 970	pound per foot
0.055 997 5	pound per inch

PRESSURES; WEIGHTS AND SURFACES

1 pound per square inch =

144.	pounds per sq. ft.
2.306 65	feet of water
0.703 067	meter of water
0.070 306 7	kilogram per sq. centimeter

1 pound per square foot =

0.016 018 4	foot of water
0.006 944 44	pound per sq. inch
0.004 882 41	meter of water
4.882 41	kilogram per sq. meter

1 pound per cubic foot =

27.	pounds per cubic yard
0.133 681	pounds per U. S. gallon
16.018 4	kilograms per cubic meter

1 kilogram per square centimeter =

10,000.	kilograms per sq. meter
10.	meters of water
2,048.17	pounds per square foot
32.808 3	feet of water
14.223 4	pounds per square inch

1 kilogram per square meter =

0.001	meter of water
0.001 422 34	pound per sq. inch
0.204 817	pound per sq. foot
0.003 280 83	foot of water

1 kilogram per cubic meter =

1.685 56	pounds per cubic yard
0.062 428 3	pound per cubic foot

WORK

1 foot-pound =

0.001 818 18	horse-power-second
0.000 376 591	watt-hour
0.138 255	kilogram-meter

1 horse-power-second =

550.	foot-pounds
0.207 125	watt-hour

1 horse-power-hour =

1,980,000.	foot-pounds
3,600.	horse-power-seconds
745.650	watt-hours
0.745 650	kilowatt-hour
273,745.	kilogram-meters

1 watt-hour =

1.	ampere-hour x one volt
0.001	kilowatt-hour
2,655.403	foot-pounds
0.001 341 11	horse-power-hour

1 kilowatt-hour =

1,000.	watt-hours
367,123.	kilogram-meters
2,655,403.	foot-pounds
4,828.01	h.-power-seconds
1.341 11	horse-power-hours

1 kilogram-meter =

0.002 723 88	watt-hour
7.233 00	foot-pounds
0.013 150 9	U. S. h.-p.-second
0.013 333 33	metric h.-p.-second

POWER OR RATE OF DOING WORK

1 horse-power =

33,000.	foot-pounds per minute
550.	foot-pounds per second
4,562.42	kilogram-meters per minute
745.650	watts
0.745 650	kilowatt
1.013 87	metric h.-power
1.	second-foot of water falling 8.8 ft.

1 metric horse-power or French horse-power or cheval vapeur =

32,548.5	foot-pounds per minute
542.475	foot-pounds per second
0.986 318	horse-power
735.448	watts
0.735 448	kilowatt
4,500.	kilogram-meters per minute
75.	kilogram-meters per second

1 kilowatt =

2,655,402.	foot-pounds per hour
44,256.7	foot-pounds per minute
737.612	foot-pounds per second
1.341 11	horse-power
1,000.	watts

1 watt =

1.	ampere per second at one volt
44.256 7	foot-pounds per minute
0.737 612	foot-pound per second
0.001 341 11	horse-power
0.001	kilowatt

LINEAR VELOCITIES

1 foot per second =

60.	feet per minute
0.681 818	mile per hour
0.011 363 6	mile per minute
18.288 0	meters per minute
0.304 801	meter per second
1.097 28	kilometers per hour

1 foot per minute =

0.016 666 7	foot per second
0.011 363 6	mile per hour
0.304 801	meter per minute

1 mile per hour =

88.	feet per minute
1.466 67	feet per second
0.016 666 7	mile per minute
26.822 4	meters per minute
1.609 35	kilometers per hour

1 mile per minute =

88.	feet per second
60.	miles per hour
1.609 35	kilometers per minute

1 meter per second =

196.850	feet per minute
3.280 83	feet per second
2.236 93	miles per hour

WEIGHTS, VOLUMES AND COMPOUND FACTORS OF WATER*

1 U. S. gallon =

8.345 45	pounds
231.	cubic inches
0.133 681	cubic foot
3.785 43	kilograms

1 English gallon (Imperial) =

10.022 1	pounds
277.41	cubic inches
0.160 538	cubic foot
4.545 963 1	kilograms

1 cubic inch =

0.578 040	ounce
0.036 127 5	pound

1 cubic foot =

62.428 3	pounds*
0.031 214 2	ton (short)
0.027 869 8	ton (long)
7.480 52	U. S. gallons
28.317 0	kilograms
28.317 0	liters

* At 50° F. one cubic foot of water weighs 62.408 pounds.

WEIGHTS, VOLUMES AND COMPOUND FACTORS OF WATER—*Continued*

1,000,000 cubic feet =

22.956 8	acre-feet

1 liter =

1.	kilogram
2.204 62	pounds
61.023 4	cubic inches
0.035 314 5	cubic foot
0.264 170	U. S. gallon

1 hectoliter =

100.	kilograms
220.462	pounds
0.110 231	ton (short)
0.098 420 6	ton (long)
3.531 45	cubic feet

1 pound =

27.679 7	cubic inches
0.016 018 4	cubic foot
0.119 826	U. S. gallon
0.099 779 2	English gallon
0.453 592	liter
0.004 535 92	hectoliter

1 ton (short) =

2,000.	pounds
32.036 7	cubic feet
9.071 85	hectoliters
239.652	U. S. gallons

1 ton (long) =

2,240.	pounds
35.881 1	cubic feet
10.160 5	hectoliters
268.410 24	U. S. gallons

1 ton (metric) =

2,204.62	pounds
35.314 5	cubic feet
10.	hectoliters
1.	cubic meter

1 kilogram =

2.204 62	pounds
61.023 4	cubic inches
0.035 314 5	cubic foot
0.264 170	U. S. gallon
0.219 975	English gallon
0.01	hectoliter

1 California miner's inch =

0.025	cubic foot per second
1.5	cubic feet per minute
0.187 013	U. S. gallon per second
11.220 78	U. S. gallons per minute
0.000 707 925	cubic meter per second
1.	horse-power at 80 per cent efficiency when the head is 440 feet

1 cubic foot per second (known as "second-foot") =

646,316.9	U. S. gallons per day of 24 hours
26,929.872	U. S. gallons per hour
448.831 2	U. S. gallons per minute
7.480 52	U. S. gallons per second
40.	California miner's inches
60.	cubic feet per minute
1.983 47	acre-feet per day of 24 hours
.991 735 5	acre-inch per hour
101.941	cubic meters per hour
100.	horse-power at 80 per cent efficiency when the head is 1,100 feet

1 cubic foot per minute =

10,771.948	U. S. gallons per day of 24 hours
448.831	U. S. gallons per hour
7.480 52	U. S. gallons per minute
0.666 667	California miner's inch
0.016 667	cubic foot per second
0.033 057 85	acre-foot per day of 24 hours
1.699 02	cubic meters per hour
1.	horse-power at 80 per cent efficiency when the head is 660 feet

WEIGHTS, VOLUMES AND COMPOUND FACTORS OF WATER—*Continued*

1,000,000 U. S. gallons per day of 24 hours =

1.547 228	cubic feet per second
92.833 67	cubic feet per minute
61.889 1	California miner's inches
41,666.666 7	U. S. gallons per hour
694.444	U. S gallons per minute
11.574	U. S. gallons per second
3.068 883 3	acre-feet per day of 24 hours

1 cubic foot per second for one day of 24 hours (run-off) =

0.003 099 174	square-mile foot
0.037 190 082	square-mile inch

1 U. S. gallon per minute =

0.002 228 009	cubic-foot per second
0.004 420 19	acre-foot per day of 24 hours

1 acre-foot is a body of water 1 acre in area and 1 foot in depth =

325,851.	U. S. gallons
43,560.	cubic feet
1,613.33	cubic yards
1,233.49	cubic meters
0.018 75	square-mile-inch
0.504 17	cubic-feet per second for 24 hours

1 square-mile-inch =

53.33	acre-feet
2,323,200.	cubic feet
17,378,733.	U. S. gallons

1 inch in depth =

27,154.3	U. S. gallons per acre
0.623 376 6	U. S. gallon per square foot
3,630.	cubic feet per acre
254.000 5	cubic meters per hectare

1 foot in depth =

43,560.	cubic feet per acre
67.324 7	U. S. gallons per square yard
3,048.01	cubic meters per hectare

1 centimeter in depth =

10.	liters per square meter
1,429.13	cubic feet per acre
0.245 576	U. S. gallon per square foot

1 cubic foot per acre =

0.000 275 482	inch in depth
0.000 699 727	centimeter in depth

1 cubic inch per square foot =

0.006 944 4	inch in depth
0.017 638 958	centimeter in depth

WEIGHTS, VOLUMES AND COMPOUND FACTORS OF WATER—*Continued*

1 U. S. gallon per square foot =

1.604 17	inches in depth
4.074 59	centimeters in depth

1 cubic foot per acre per second =

1.983 47	feet depth per day of 24 hours

1 U. S. gallon per acre per second =

0.132 575 7	inch per hour
0.265 152	foot per day of 24 hours

1 foot per second =

26,929.87	U. S. gallons per square foot per hour

Water is at its greatest density at 39.2° F. Sea water is 1.6 to 1.9 heavier than fresh water.

ERRATA

Page 89. Formula on fourth line should read :

$$K = 0.762 \times D^2 \times L \times V^2$$

Formulas on eighth, ninth and tenth lines should read :

$$K = \frac{W \times a \times V^3}{2g \times 144} = \frac{W \times a \times V^3}{9259} = 0.000108 \times W \times a \times V^3.$$

Page 90. Second formula under "Capacity of Cylindrical Tanks," should read:

Capacity in gallons $= \frac{0.7854\ D^2 \times L}{0.13368} = 5.87\ D^2 \times L$; where L is length of pipe in feet.

Page 91. Formula on second line should read

$\sqrt{2 \times 32.15} = 8.03$

Page 98. Eleventh line should read:

Water is at its greatest density at 39.2° F. Sea water is from 1.6 to 1.9 pounds per cubic foot heavier than fresh water.

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WEIGHTS, VOLUMES AND COMPOUND FACTORS OF WATER—*Continued*

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0.265 152	foot per day of 24 hours

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Water is at its greatest density at 39.2° F. Sea water is 1.6 to 1.9 heavier than fresh water.

ABNER DOBLE COMPANY BULLETINS

We plan to publish bulletins from time to time relating to our water-wheel and other hydraulic products, notable hydro-electric developments, iron and steel goods, and other lines of work in which we are concerned. Following is a list of our present bulletins and others which we have in preparation:

Bulletin No. 3. Iron and Steel.
Bulletin No. 4. Tools.
Bulletin No. 5. Tangential Water Wheels (out of print).
Bulletin No. 6. An Investigation of the Doble Needle Regulating Nozzle (Mass. Inst. of Tech.).
Bulletin No. 7. Doble Tangential Water Wheels (Superseding Bulletin No. 5).
Bulletin No. 8. Hydro-Electric Power Development and Transmission in California (Tech. Soc. of Pac. Coast).
Bulletin No. 9. The Irrigation System of Ontario, California (Am. Soc. C. E.).
Bulletin No. 10. Cornell University and Its New Hydro-Electric Power Plant (in preparation).

If you are interested in any of the above bulletins kindly address us stating in what line of work you are engaged.

ABNER DOBLE COMPANY,

Fremont and Howard Sts.,

San Francisco, Cal.

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